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A SURVEY OF AVAILABLE DATA ON THE NORMAL DRAG COEFFICIENT OF CA--ETC(U)

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CIVIL ENGINEERING LABORATORY  
Naval Construction Battalion Center  
Port Hueneme, California

Sponsored by  
NAVAL FACILITIES ENGINEERING COMMAND  
and  
NOAA DATA BUOY OFFICE

**A SURVEY OF AVAILABLE DATA ON THE NORMAL DRAG  
COEFFICIENT OF CABLES SUBJECTED TO CROSS-FLOW**

August 1977

An Investigation Conducted by

MAR, INCORPORATED  
Rockville, Maryland

N62583-77-M-R443



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The Civil Engineering Laboratory is conducting a research program with the goal of developing mathematical models to aid in the computer simulation of the behavior of cable structures in the ocean. One of the major goals of the program has been prediction of the normal drag of a vibrating cable. Two simulation models have been independently developed which, when used together, result in the capability of predicting the normal drag		

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of a vibrating cable. The models predict the frequency and amplitude of the cable vibrations based upon the mechanical properties of the cable and the fluid flow properties; a factor is then computed which, when multiplied by the non-vibrating drag coefficient for the cable, results in the effective drag coefficient for the cable. Thus, the non-vibrating drag coefficient must be known. A survey has been conducted to identify available drag coefficient of non-vibrating cables and to assess the quality of the data as to its applicability for use in design of undersea cable structures.

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## Section 1

### INTRODUCTION

The Civil Engineering Laboratory is conducting a research program with the goal of developing mathematical models to aid in the computer simulation of the behavior of cable structures in the ocean. One of the major aspects of the program has been in the area of predicting the normal drag of a vibrating cable. Two simulation models have been independently developed which, when used together, result in the capability of predicting the normal drag of a vibrating cable. The first of the two models predicts the frequency and amplitude of the cable vibrations based upon the mechanical properties of the cable and the fluid flow field properties. The second model uses the frequency and amplitude of the cable vibrations and computes a factor which, when multiplied by the non-vibrating drag coefficient for the cable, results in the vibrating drag coefficient for the cable. Therefore, in order to compute the drag coefficient of a vibrating cable using these two models the non-vibrating drag coefficient must be known. As a result, a survey was conducted to identify what drag coefficient data of non-vibrating cables are available and to assess the quality of the data as to its applicability for use in the models described above.

## Section 2

### PRESENTATION AND DISCUSSION OF DATA ITEMS

In this section the data which were collected during the course of the survey are presented in tabulated and plotted forms. The data items are organized in terms of the source of the data, that is, by the author of the report or the investigator. Where possible, a discussion of the experimental techniques used to generate the data and an assessment of the quality of the data is presented for each data item. Each data item may contain drag coefficient data for more than one type of cable. For those cases in which more than one cable is presented and where the cables are greatly dissimilar in type or construction, then the data are presented in separate tables and graphs.

## 2.1 DATA ITEM 1

**Source:** Relf, E.F., and Powell, C. H., "Tests on Smooth and Stranded Wires Inclined to the Wind Direction, and a Comparison of Results on Stranded Wire in Air and Water", Advisory Committee for Aeronautics, Great Britain, Reports and Memoranda (New Series) No. 307, January 1917.

**Cables Tested:** The investigators tested three (3) cables which are described as follows:

- a. 1¼ inch British Cable, measured circumference 1.22 inches,  
6 x 24 construction
- b. 1½ inch British Cable, measured circumference 1.57 inches,  
6 x 37 construction
- c. 1-3/8 inch German Cable, measured circumference 1.38 inches,  
7 x 7 construction.

In addition, data from previous tests for two (2) other cables are presented in the report by Relf and Powell. These are:

- d. 3 inch circumference cable unknown construction, and
- e. 4/5 inch diameter stranded wire, 7 x 14 construction. (This diameter is an approximate value, determined from known Reynolds number and air flow velocity values and a mean kinematic viscosity from the four previous cable tests.)

**Experimental Procedure:** A 30 inch long sample of cable was mounted horizontally in a wind tunnel by a 1/8-inch spindle at the center of the sample. The normal drag force was measured and corrected for end effects. The data were presented by Relf and Powell in terms of:

$$\frac{\text{normal drag per foot}}{\rho d V^2}$$

versus Reynolds number. The data presented in this report have been recalculated to obtain the normal drag coefficient

$$C_d = \frac{\text{normal drag per foot}}{\frac{1}{2} \rho d V^2}$$

**Assessment of the Data:** The actual amount of data presented is very small with only one data point per cable, however, there is no evidence to indicate that the data is of poor quality. No measurement of cable vibrations were made, nor were observations of vibrations reported.

**Drag Coefficient Data:** The cable normal drag coefficient data is presented in Table 2-1 and Figure 2-1.

**Table 2-1. Drag Coefficient Data for Data Item 1**

CABLE	$Re_d$	$C_d$
1¼" British Cable	$8.128 \times 10^3$	1.204
1½" British Cable	$1.045 \times 10^4$	1.124
1-3/8" German Cable	$9.183 \times 10^3$	1.228
3" Cable	$1.483 \times 10^4$	1.080
4/5" Stranded Wire	$4.000 \times 10^3$	0.978
	$5.333 \times 10^3$	1.028

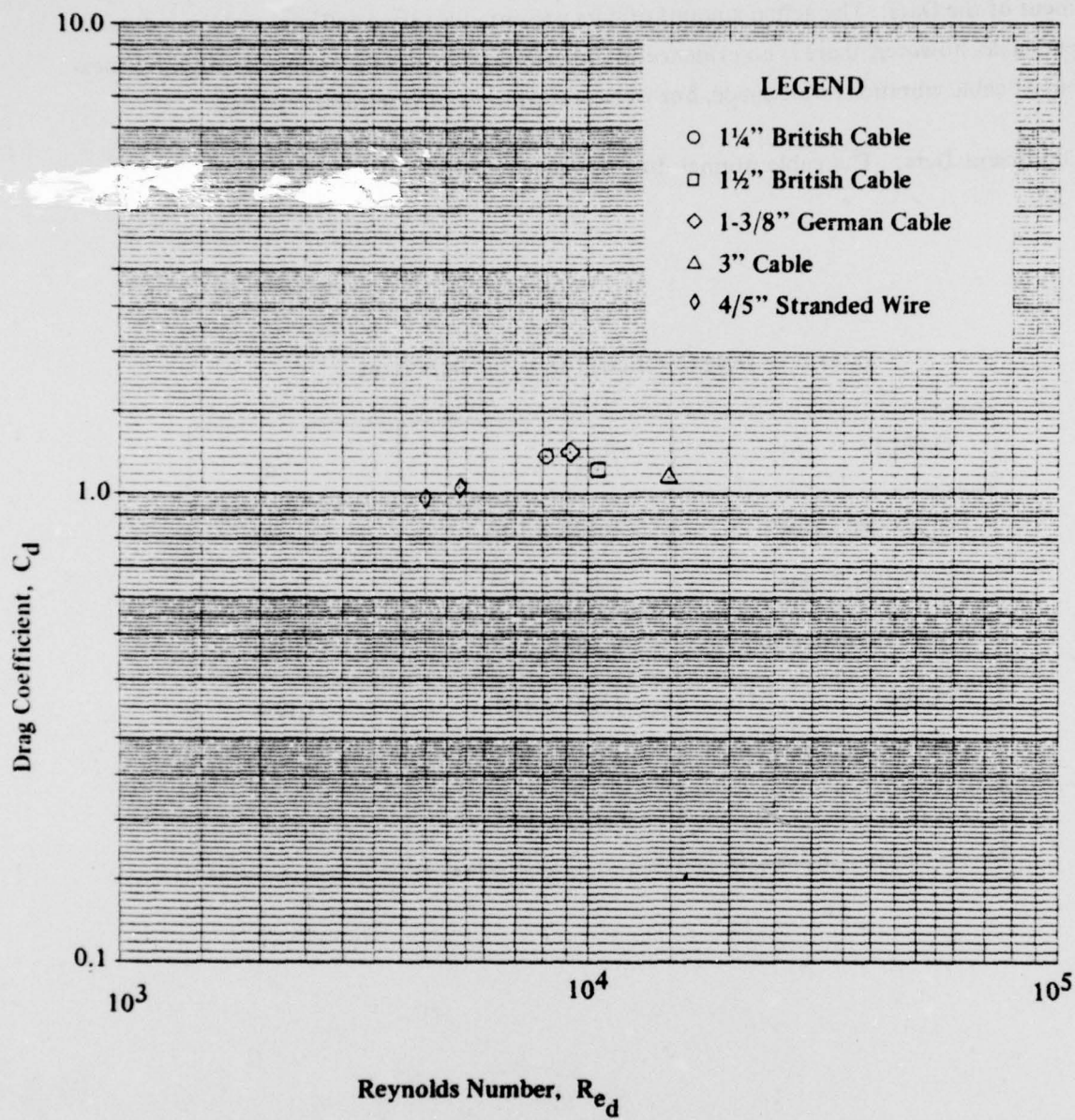


Figure 2-1. Drag Coefficient Data by Relf and Powell of Stranded Wire Cables

## 2.2 DATA ITEM 2

Source: Pode, Leonard, "An Experimental Investigation of the Hydrodynamic Forces on Stranded Cables", David Taylor Model Basin, Report 713, May 1950.

Cables Tested: Eight samples of cable were tested, four of 1/16-inch diameter, three of 1/8-inch diameter, and one of 1/4-inch diameter. The eight cables tested are as follows:

a.	1/16-inch	19 wire strand construction
b.	1/16-inch	7 x 7 construction
c.	1/16-inch	7 x 7 construction
d.	1/16-inch	7 x 7 construction
e.	1/8-inch	7 x 7 construction
f.	1/8-inch	7 x 19 construction
g.	1/8-inch	7 x 19 construction
h.	1/4-inch	7 x 19 construction

Experimental Procedure: Samples of the cables approximately sixty (60) feet in length were towed from the towing carriage in the NSRDC deep water basin at speeds ranging from 3 knots to 16 knots. The true cable angle was measured using an arrangement of two optical devices: a travelling telescope and a sighting transit. These measurements enabled the computation of the direction cosines of the line of the cable. Knowing the cable angles and the weight of the cable in water, the drag coefficient can be determined from a summation of forces normal to the cable,

$$N = W m \cot \phi$$

where  $N$  is the normal hydrodynamic force per unit length,  $W$  is the cable weight per unit length in water,  $m$  is the direction cosine of the cable in the direction of gravity, and  $\phi$  is the angle between the cable and the velocity stream. Having computed the normal force,  $N$ , the normal force coefficient,  $C_N$ , can be computed by

$$C_N = \frac{N}{\frac{1}{2} \rho V^2 d}$$

where  $\rho$  is the fluid density,  $V$  is the towspeed and  $d$  is the cable diameter. The drag coefficient of a cable perpendicular to the velocity vector can then be computed using the sine squared principle,

$$C_d = \frac{C_N}{\sin^2 \phi}$$

**Assessment of the Data:** Although it is felt that the quality of Pode's data is good, there are certain factors which should be brought out concerning the meaning of the data. First, the data represents towing configurations in the critical angle range. That is, the cable angles were very shallow, ranging from about one (1) degree to less than ten (10) degrees. This regime of cable angles does not reflect the typical mooring scenario. Second, the sine squared law was used to compute the drag coefficient,  $C_d$ . Although this is a common practice for steep angle configurations, there is no conclusive evidence that the sine squared principle is valid for very shallow angles. It can be shown that a one-half degree error in the measurement of the cable angle can result in as much as a 25 percent error in the value of  $C_d$ . Lastly, Pode makes no mention of cable vibrations. Based upon similiar experiments by other investigators, it is felt that it is highly likely that the cables did vibrate under some test conditions.

**Drag Coefficient Data:** Pode's drag coefficient data are presented in Table 2-2. The cable designations A through H are as described previously. Figure 2-2 shows the plotted drag coefficients as a function of Reynolds number.

Table 2-2. Drag Coefficient Data For Eight Stranded Wire Ropes by Pade

CABLE	REYNOLDS NUMBER	$C_d$
A ↓	$2.886 \times 10^3$	1.53
	$3.607 \times 10^3$	1.62
	$4.314 \times 10^3$	1.80
	$5.050 \times 10^3$	1.79
	$5.786 \times 10^3$	1.85
	$6.507 \times 10^3$	1.99
	$7.200 \times 10^3$	2.13
B ↓	$2.171 \times 10^3$	1.81
	$2.900 \times 10^3$	1.76
	$3.629 \times 10^3$	1.60
	$4.328 \times 10^3$	1.36
	$5.072 \times 10^3$	1.36
	$5.800 \times 10^3$	1.43
	$6.514 \times 10^3$	1.53
C ↓	$7.207 \times 10^3$	1.69
	$2.886 \times 10^3$	1.58
	$3.621 \times 10^3$	1.46
	$4.328 \times 10^3$	1.39
	$4.336 \times 10^3$	1.35
	$5.079 \times 10^3$	1.36
	$5.757 \times 10^3$	1.55
	$5.786 \times 10^3$	1.41
	$6.507 \times 10^3$	1.47
	$7.214 \times 10^3$	1.59
	$7.214 \times 10^3$	1.51

Table 2-2. Drag Coefficient Data For Eight Stranded Wire Ropes by Pade (Cont.)

CABLE	REYNOLDS NUMBER	C <sub>d</sub>
D ↓	2.878 x 10 <sup>3</sup>	1.71
	2.886 x 10 <sup>3</sup>	1.73
	2.886 x 10 <sup>3</sup>	1.69
	3.607 x 10 <sup>3</sup>	1.31
	3.614 x 10 <sup>3</sup>	1.57
	4.328 x 10 <sup>3</sup>	1.37
	4.328 x 10 <sup>3</sup>	1.66
	4.328 x 10 <sup>3</sup>	1.44
	5.043 x 10 <sup>3</sup>	1.50
	5.064 x 10 <sup>3</sup>	1.42
	5.757 x 10 <sup>3</sup>	1.58
	5.778 x 10 <sup>3</sup>	1.46
	6.478 x 10 <sup>3</sup>	1.66
	6.493 x 10 <sup>3</sup>	1.52
	7.200 x 10 <sup>3</sup>	1.88
	7.214 x 10 <sup>3</sup>	1.61
	7.936 x 10 <sup>3</sup>	2.02
	8.657 x 10 <sup>3</sup>	2.06
	9.378 x 10 <sup>3</sup>	2.44
	9.955 x 10 <sup>3</sup>	2.47
E ↓	7.185 x 10 <sup>3</sup>	1.46
	7.214 x 10 <sup>3</sup>	1.40
	8.657 x 10 <sup>3</sup>	1.37
	8.671 x 10 <sup>3</sup>	1.42
	8.686 x 10 <sup>3</sup>	1.40
	1.010 x 10 <sup>4</sup>	1.29
	1.011 x 10 <sup>4</sup>	1.33
	1.014 x 10 <sup>4</sup>	1.28

Table 2-2. Drag Coefficient Data For Eight Stranded Wire Ropes by Pode (Cont.)

CABLE	REYNOLDS NUMBER	$C_d$
<div style="display: flex; align-items: center; justify-content: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg);">E</div> <div style="flex-grow: 1; border-left: 1px solid black; position: relative;"> <div style="position: absolute; top: 0; bottom: 0; left: -10px; right: -10px;"></div> <div style="position: absolute; bottom: 0; left: 0; right: 0; text-align: center;">F</div> </div> </div>	$1.156 \times 10^4$	1.17
	$1.157 \times 10^4$	1.10
	$1.159 \times 10^4$	1.08
	$1.291 \times 10^4$	1.20
	$1.299 \times 10^4$	1.10
	$1.301 \times 10^4$	1.12
	$1.440 \times 10^4$	1.17
	$1.443 \times 10^4$	1.12
	$1.444 \times 10^4$	1.17
	$1.576 \times 10^4$	1.23
	$1.580 \times 10^4$	1.25
	$1.721 \times 10^4$	1.30
	$1.721 \times 10^4$	1.38
	$1.868 \times 10^4$	1.49
	$1.873 \times 10^4$	1.25
	$2.010 \times 10^4$	1.61
	$2.010 \times 10^4$	1.49
	$2.158 \times 10^4$	1.67
	$2.158 \times 10^4$	1.65
	$2.304 \times 10^4$	1.69
	$2.307 \times 10^4$	1.53
	$7.214 \times 10^3$	1.37
	$7.229 \times 10^3$	1.33
	$7.243 \times 10^3$	1.43
	$8.556 \times 10^3$	1.45
	$8.642 \times 10^3$	1.34
	$8.686 \times 10^3$	1.36
	$1.010 \times 10^4$	1.25

Table 2-2. Drag Coefficient Data For Eight Stranded Wire Ropes by Pade (Cont.)



CABLE	REYNOLDS NUMBER	$C_d$
<div style="display: flex; align-items: center; justify-content: center;"> <div style="text-align: center; margin-right: 10px;"> <p>F</p>  </div> </div>	$1.014 \times 10^4$	1.21
	$1.153 \times 10^4$	1.06
	$1.154 \times 10^4$	0.92
	$1.157 \times 10^4$	0.93
	$1.297 \times 10^4$	1.09
	$1.299 \times 10^4$	0.93
	$1.300 \times 10^4$	0.98
	$1.438 \times 10^4$	0.97
	$1.440 \times 10^4$	1.49
	$1.587 \times 10^4$	1.18
	$1.731 \times 10^4$	1.21
	$1.731 \times 10^4$	1.09
	$1.876 \times 10^4$	1.16
	$2.020 \times 10^4$	1.23
	$2.158 \times 10^4$	1.38
	$2.301 \times 10^4$	1.53
	$7.214 \times 10^3$	1.30
	$7.214 \times 10^3$	1.26
	$8.657 \times 10^3$	1.34
	$8.657 \times 10^3$	1.29
<div style="display: flex; align-items: center; justify-content: center;"> <div style="text-align: center; margin-right: 10px;"> <p>G</p>  </div> </div>	$8.686 \times 10^3$	1.27
	$1.010 \times 10^4$	1.14
	$1.010 \times 10^4$	1.17
	$1.013 \times 10^4$	1.16
	$1.51 \times 10^4$	1.03
	$1.153 \times 10^4$	1.01
	$1.157 \times 10^4$	0.99

Table 2-2, Drag Coefficient Data For Eight Stranded Wire Ropes by Pade (Cont.)

CABLE	REYNOLDS NUMBER	$C_d$
<div style="display: flex; align-items: center; justify-content: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg);">G</div> <div style="flex-grow: 1; border-left: 1px solid black; margin: 0 10px;"></div> <div style="writing-mode: vertical-rl; transform: rotate(180deg);">H</div> </div>	$1.296 \times 10^4$	1.10
	$1.299 \times 10^4$	1.10
	$1.301 \times 10^4$	1.17
	$1.438 \times 10^4$	1.25
	$1.440 \times 10^4$	0.81
	$1.443 \times 10^4$	1.04
	$1.443 \times 10^4$	0.89
	$1.577 \times 10^4$	0.84
	$1.721 \times 10^4$	1.14
	$1.726 \times 10^4$	1.02
	$1.863 \times 10^4$	0.98
	$1.866 \times 10^4$	1.63
	$2.010 \times 10^4$	1.25
	$2.013 \times 10^4$	1.57
	$2.150 \times 10^4$	1.50
	$2.164 \times 10^4$	1.90
	$2.304 \times 10^4$	1.07
	$2.306 \times 10^4$	2.40
	$2.020 \times 10^4$	1.22
	$2.303 \times 10^4$	1.30
	$2.309 \times 10^4$	1.23
	$2.583 \times 10^4$	1.30
	$2.591 \times 10^4$	1.19
	$2.880 \times 10^4$	1.20
	$2.886 \times 10^4$	1.25
	$2.886 \times 10^4$	1.34
	$2.886 \times 10^4$	1.26
	$3.160 \times 10^4$	1.41

Table 2-2. Drag Coefficient Data For Eight Stranded Wire Ropes by Pade (Cont.)

CABLE	REYNOLDS NUMBER	$C_d$
<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">H</div> <div style="flex-grow: 1; border-left: 2px solid black; position: relative;"> <div style="position: absolute; bottom: -10px; left: 0; right: 0; text-align: center;">↓</div> </div> </div>	$3.166 \times 10^4$	1.26
	$3.174 \times 10^4$	1.19
	$3.451 \times 10^4$	1.29
	$3.463 \times 10^4$	1.40
	$3.463 \times 10^4$	1.28
	$3.737 \times 10^4$	1.14
	$3.751 \times 10^4$	1.39
	$4.017 \times 10^4$	1.58
	$4.025 \times 10^4$	1.45
	$4.028 \times 10^4$	1.43
	$4.040 \times 10^4$	1.40
	$4.271 \times 10^4$	1.42
	$4.328 \times 10^4$	1.34
	$4.591 \times 10^4$	1.57
	$4.608 \times 10^4$	1.45
	$4.617 \times 10^4$	1.34

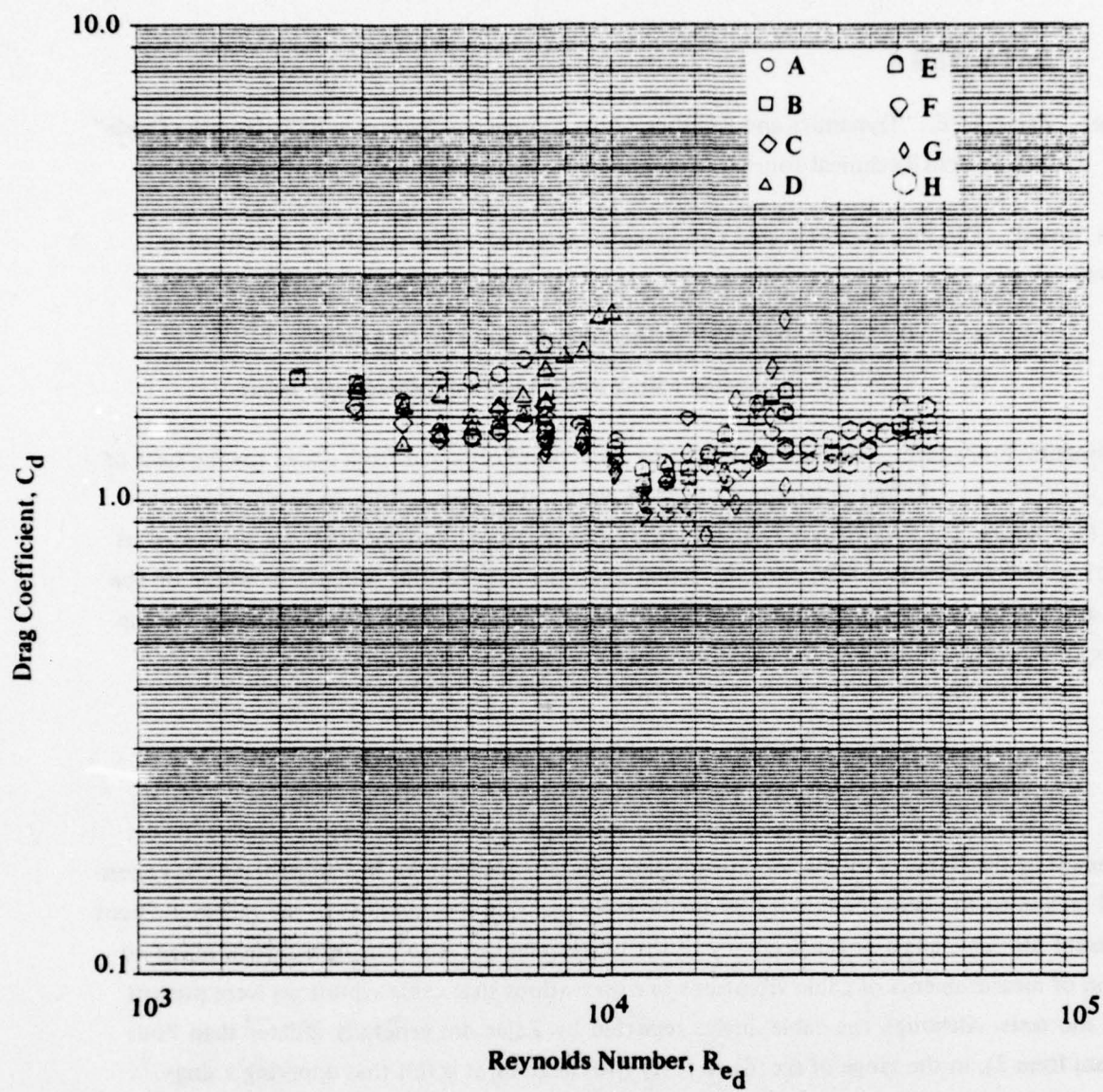


Figure 2-2. Drag Coefficient Data By Pade of  
Eight Stranded Wire Ropes

### 2.3 DATA ITEM 3

Source: Zajac, E. E., "Dynamics and Kinetics of the Laying and Recovery of Submarine Cable", Bell System Technical Journal, Volume 36(5), September 1957, pp. 1129-1207.

Cables Tested: The investigator tested two jacketed armored cables which are described as follows:

- a. 0.75 inch steel cable with a smooth polyethylene jacket
- b. 1.25 inch steel cable with a rough tar-impregnated jute jacket.

Experimental Procedure: The data presented by Zajac were obtained from at-sea towing tests of cables of 20 feet to 100 feet in length. The cables were towed over a range of speeds from 1½ knots to 9 knots. The cable angle (critical angle) was measured and the data are presented as plots of critical angle versus towing speed. Based upon the data for the weights in water of the cables and the water density, the drag coefficients were calculated using the relationship for the balance of the forces normal to the cable and the sine-squared relationship. That is,

$$C_d = \frac{w \cos \phi}{\frac{1}{2} \rho V^2 d \sin^2 \phi}$$

Assessment of the Data: Virtually no information was provided by the investigator on the experimental technique to assess the quality of the data. No mention was made as to the technique used to measure the cable angle or the accuracy of the measurements. Also, the investigator made no mention of measurements of cable vibrations or observations that cable vibrations were present during the tests. Although the cable angles reported by Zajac are generally greater than Pode (see Data Item 2), in the range of six (6) to forty (40) degrees, it is felt that applying a sine-squared relationship may not result in good quality data for the drag coefficient. The reasons for this as stated previously, are that the sine-squared relationship may not closely apply to shallow angle cables, and a small error in the measurement of the angle can result in a significant error in the computation of the drag coefficient.

Drag Coefficient Data: The drag coefficient data by Zajac are presented in Tables 2-3 and 2-4, and Figures 2-3 and 2-4 for the two cables identified.

Table 2-3. Drag Coefficient Data by Zajac for a  
Smooth Jacketed Steel Cable

REYNOLDS NUMBER	$C_d$
$7.89 \times 10^3$	1.16
$8.42 \times 10^3$	1.56
$9.21 \times 10^3$	1.18
$1.05 \times 10^4$	1.10
$1.37 \times 10^4$	0.95
$1.58 \times 10^4$	1.60
$1.58 \times 10^4$	1.70
$2.10 \times 10^4$	0.72
$2.10 \times 10^4$	1.42
$2.10 \times 10^4$	1.78
$2.63 \times 10^4$	0.79
$2.63 \times 10^4$	1.24
$3.16 \times 10^4$	1.02
$3.16 \times 10^4$	1.24
$3.16 \times 10^4$	1.53
$3.68 \times 10^4$	0.91
$3.68 \times 10^4$	0.91
$3.68 \times 10^4$	1.13
$4.21 \times 10^4$	0.86
$4.21 \times 10^4$	0.97
$4.21 \times 10^4$	1.09
$4.74 \times 10^4$	0.76
$4.74 \times 10^4$	0.98
$4.74 \times 10^4$	1.07

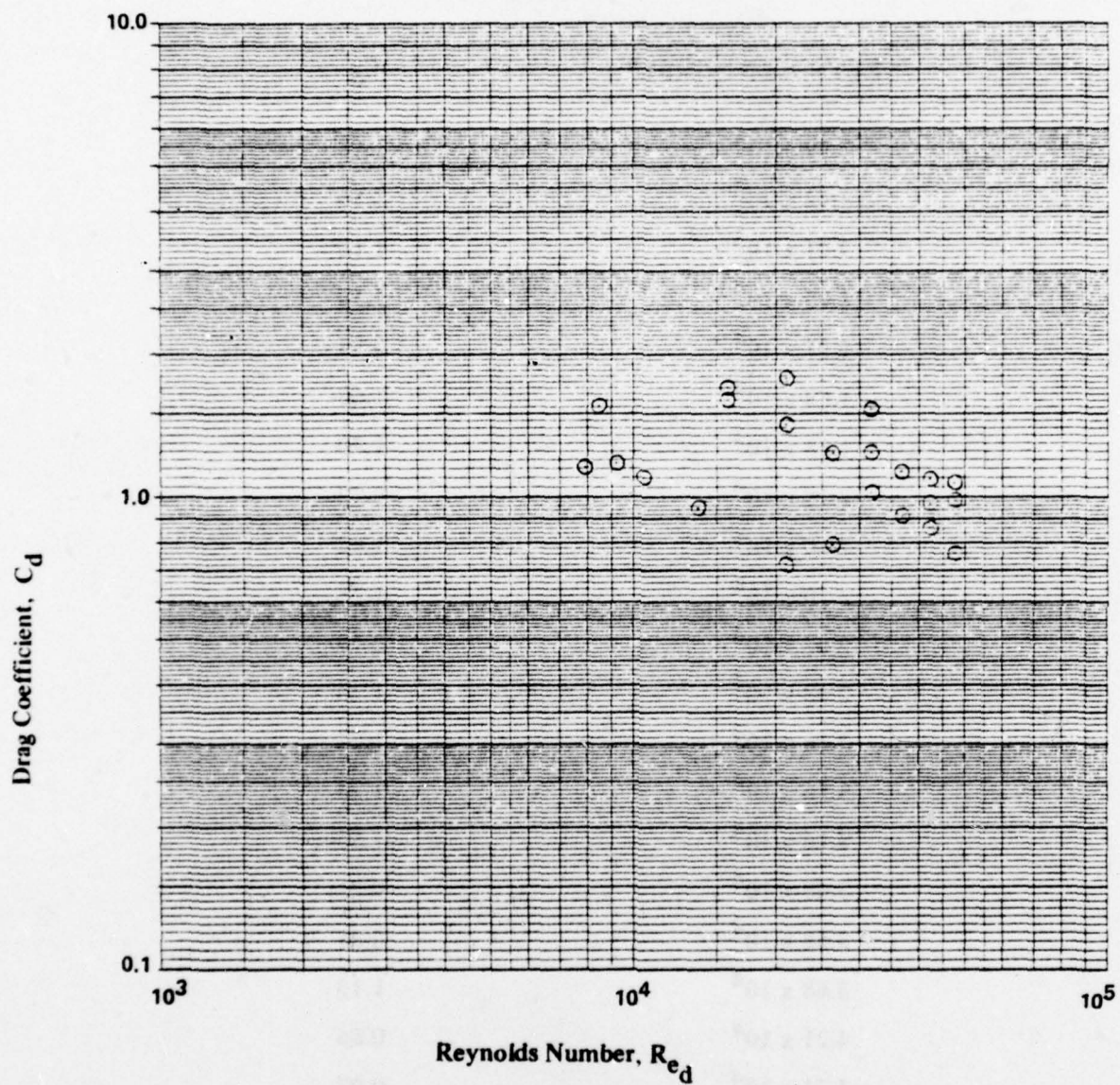


Figure 2-3. Drag Coefficient Data by Zajac for a Smooth Jacketed Steel Cable

Table 2-4. Drag Coefficient Data by Zajac for a  
Tar Impregnated Jute Jacketed Steel Cable

REYNOLDS NUMBER	$C_d$
$1.75 \times 10^4$	1.24
$1.75 \times 10^4$	1.27
$1.75 \times 10^4$	1.30
$2.63 \times 10^4$	1.44
$2.63 \times 10^4$	1.46
$2.63 \times 10^4$	1.52
$3.51 \times 10^4$	1.17
$3.51 \times 10^4$	1.19
$4.39 \times 10^4$	1.37
$4.39 \times 10^4$	1.37
$5.26 \times 10^4$	1.50
$6.14 \times 10^4$	1.10
$6.14 \times 10^4$	1.59
$6.14 \times 10^4$	1.88
$7.02 \times 10^4$	1.68
$7.89 \times 10^4$	1.50
$7.89 \times 10^4$	1.96
$7.89 \times 10^4$	2.28

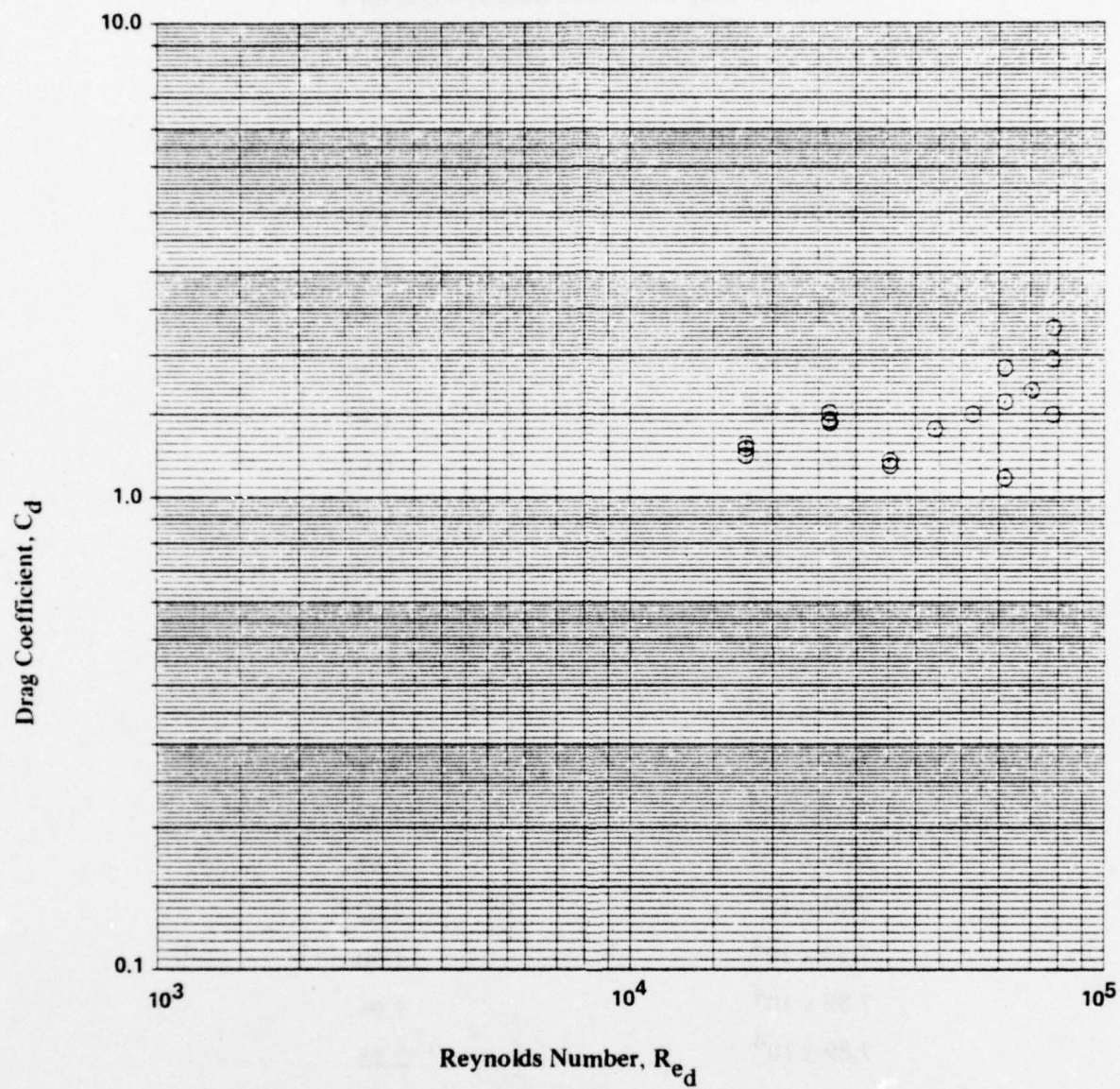


Figure 2-4. Drag Coefficient Data by Zajac for a Tar Impregnated Jute Jacketed Steel Cable

## 2.4 DATA ITEM 4

**Source:** Schultz, M. P., "Wind Tunnel Determination of the Aerodynamic Characteristics of Several Twisted Wire Ropes", David Taylor Model Basin, Report 1645, Aero Report 1028, June 1962.

**Cables Tested:** Three different cable diameters of a 12-strand, right-hand lay twisted wire rope were tested. Of the three diameters tested (0.266 inch, 0.330 inch, and 0.396 inch), only the data for the 0.396 inch cable were usable for this survey.

**Experimental Procedure:** The twisted wire ropes were mounted in the wind tunnel test section by attaching the samples to lengths of piano wire which, in turn, were mounted to a rigid frame. In order to obtain a measurable drag force, several samples of the same diameter cable were mounted in the test section at the same time. The supporting framework was attached to the wind tunnel force balance so that the entire unit could be rotated from zero degrees to 360 degrees. Measurements of lift, drag, and sideforce were taken at 20 degree intervals. Each cable was tested at four tunnel speeds.

**Assessment of the Data:** Although the forces exerted on the piano wire and support structure were deducted from the forces exerted on the entire assembly, no other corrections were made to the data to account for effects of jet boundary, wake blockage, etc. The investigator made no mention of cable vibrations, however, unsteady lift forces were noted and may be due to cable vibrations. Only the 0.396 inch cable sample was tested at an angle of 90 degrees to the flow. Therefore, the data for the remaining two cables are not presented here.

**Drag Coefficient Data:** The cable drag coefficient data for the 0.396 inch stranded wire rope are presented in Table 2-5 and Figure 2-5.

Table 2-5. Drag Coefficient Data by Schultz for A 0.396-Inch Stranded Wire Rope

REYNOLDS NUMBER	$C_d$
$2.54 \times 10^4$	1.29
$3.91 \times 10^4$	1.23
$4.53 \times 10^4$	1.19
$5.35 \times 10^4$	1.21

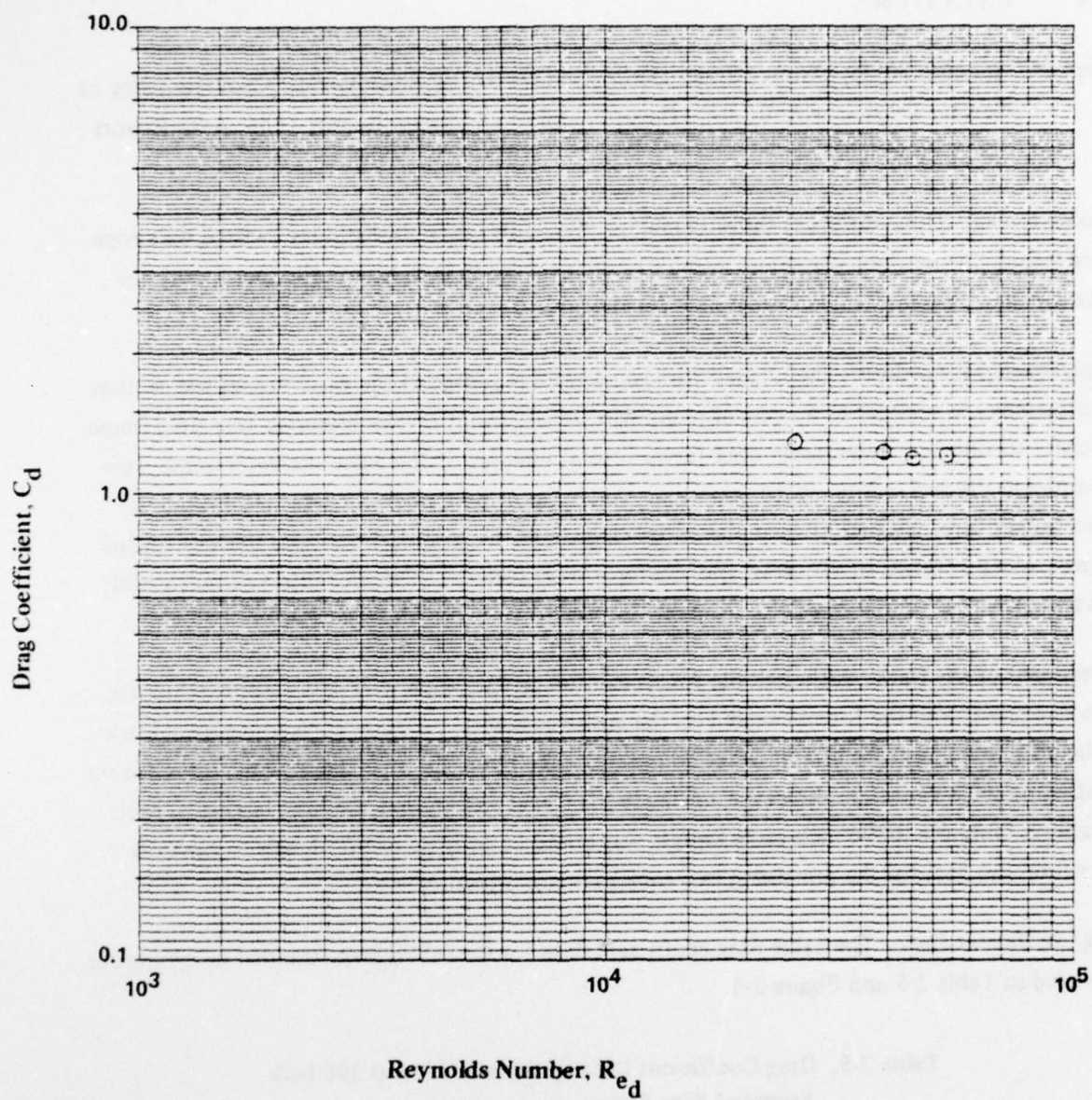


Figure 2-5. Drag Coefficient Data by Schultz for A  
0.396-Inch Stranded Wire Rope

## 2.5 DATA ITEM 5

**Source:** "Drag Measurements of Bare and Faired Cables", David Taylor Model Basin, Enclosure to TMB Letter 9250 (549:TG), May 1964.

**Cables Tested:** The cable tested was a model made up of a solid steel rod wrapped with copper wire to simulate a double-armored bare cable. The model had a diameter of 1.16 inches and was two (2) feet in length. The number of wire strands used to simulate the armored cable was not stated in the report.

**Experimental Procedure:** The cable model was mounted in the test section of the two-dimensional dynamometer such that the model was oriented 90 degrees to the flow when towed through the water basin. The tests were conducted over a speed range from 1 to 12 knots. The data were presented in the report in the form of a curve of drag per foot as a function of towing speed. The data were converted to coefficient form for presentation in this report.

**Assessment of the Data:** It is felt that the quality of the data is good with the exception of the three data points below a Reynolds Number of  $5 \times 10^4$ . Those data points are suspect because the magnitudes of the measured forces were very small and probably influenced by the accuracy of the dynamometer measuring system. The investigator stated that the model was rigid and did not vibrate. Due to the shortness of the cable model (two (2) feet), three-dimensional effects might possibly be influencing the data resulting in the data having values lower than would a long cable.

**Drag Coefficient Data:** The drag coefficient data for the 1.16 inch stranded cable are presented in Table 2-6 and Figure 2-6.

**Table 2-6. Drag Coefficient Data for A 1.16 Inch Simulated  
Double-Armored Cable**

REYNOLDS NUMBER	$C_d$
$1.484 \times 10^4$	1.822
$2.969 \times 10^4$	1.367
$4.453 \times 10^4$	1.114
$5.937 \times 10^4$	0.934
$7.421 \times 10^4$	0.933
$8.906 \times 10^4$	0.931
$1.039 \times 10^5$	0.941
$1.187 \times 10^5$	0.940
$1.336 \times 10^5$	0.936
$1.484 \times 10^5$	0.933
$1.633 \times 10^5$	0.925
$1.781 \times 10^5$	0.917

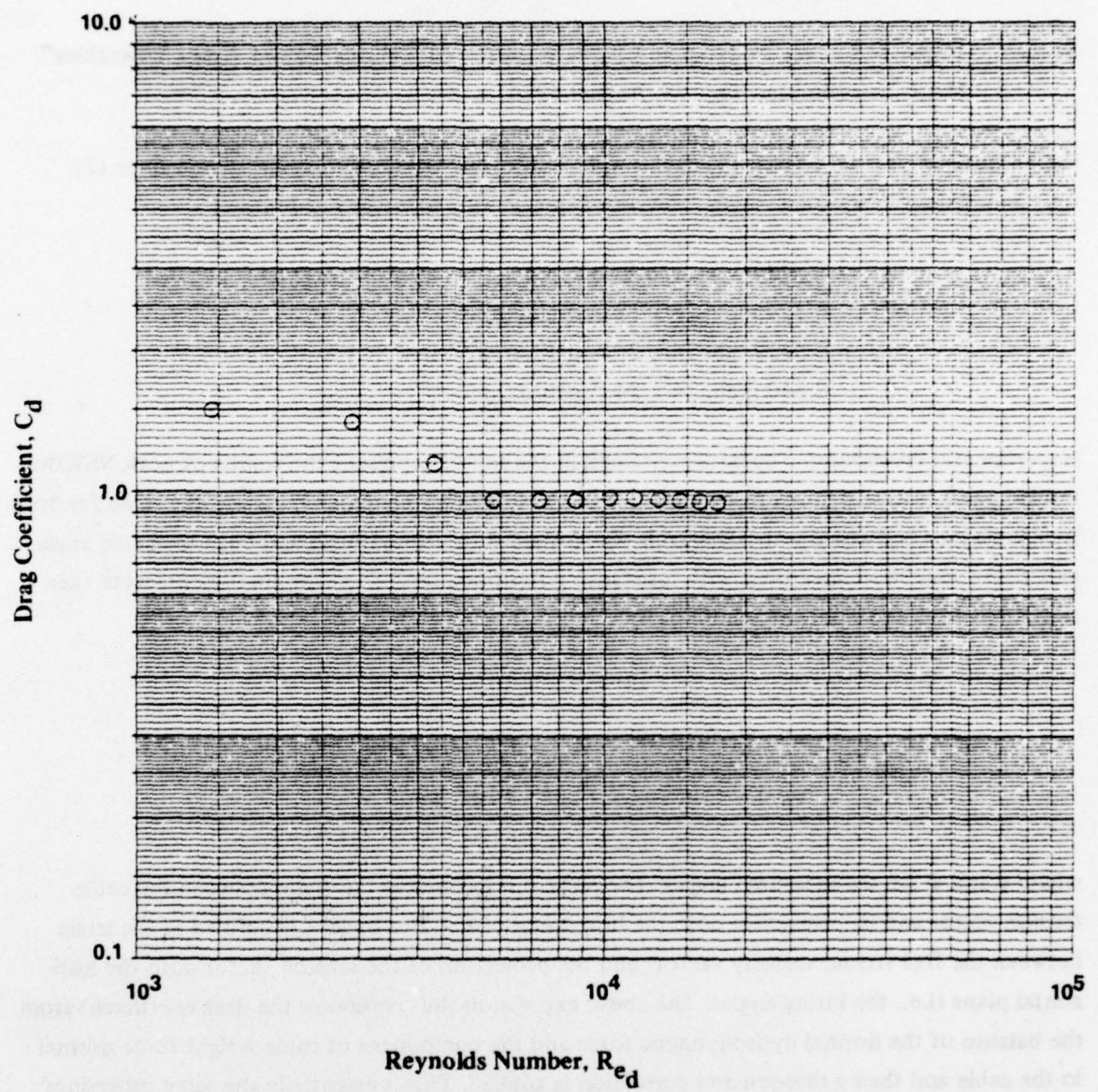


Figure 2-6. Drag Coefficient Data for A 1.16 Inch Simulated Double-Armored Cable

## 2.6 DATA ITEM 6

Source: Diggs, J. S., "Hydrodynamic Characterization of Various Towed Array Towcables", MAR, Incorporated TR-128, August 1974.

**Cables Tested:** A total of four (4) cables were tested, one (1) smooth jacketed and three (3) unjacketed double-armored cables. The four (4) cables are identified as follows:

- a. 0.375 inch smooth jacketed
- b. 0.322 inch, 18 x 18 construction
- c. 0.542 inch, 24 x 24 construction
- d. 0.840 inch, 24 x 24 construction.

**Experimental Procedure:** The data contained in the report represent the results of both NSRDC towing basin tests and at-sea towing tests. The measurement technique used was the same for both the laboratory and at-sea tests. The cable was towed at its critical angle and both the cable angle and kiting angle were measured with resistance potentiometers. The drag coefficients were then computed from the following relationship:

$$C_d = \frac{W \cos \phi \cos \psi}{\frac{1}{2} \rho d V^2 \sin^2 \phi (1 + \cot^2 \phi \sin^2 \psi)^{3/2}}$$

where  $\phi$  and  $\psi$  are the measured angles. The angle  $\phi$  is defined as the angle between the cable tension vector and its projection onto the horizontal plane. The angle  $\psi$  is defined as the angle between the free stream velocity vector and the projection of the tension vector onto the horizontal plane (i.e., the kiting angle). The above expression thus computes the drag coefficient from the balance of the normal hydrodynamic force and the component of cable weight force normal to the cable and then a sine-squared correction is applied. This is essentially the same procedure used by Pode. (See Section 2.2.)

**Assessment of the Data:** As was described in Section 2.2, there are two (2) inherent problems in determining cable drag coefficients from critical angle towing tests. The first is that a small error in the measurement of the cable angle can result in a large error in the computation of the drag coefficient. The second, not related to the experimental accuracy, is that for shallow angles

there is no evidence that the sine-squared relationship for the variation of the normal hydrodynamic force is valid. Also, it was verified by discussions with the author that the cable strumming was present when much of the data was taken.

**Drag Coefficient Data:** The drag coefficient data for the smooth jacketed cable are presented in Table 2-7 and Figure 2-7, and the remaining data for the unjacketed cables are presented in Table 2-8 and Figure 2-8.

**Table 2-7. Drag Coefficient Data by Diggs For A 0.375 inch Smooth Jacketed Cable**

REYNOLDS NUMBER	$C_d$
$2.90 \times 10^4$	1.03
$4.20 \times 10^4$	1.09
$5.85 \times 10^4$	1.15
$7.35 \times 10^4$	1.20
$8.80 \times 10^4$	1.29

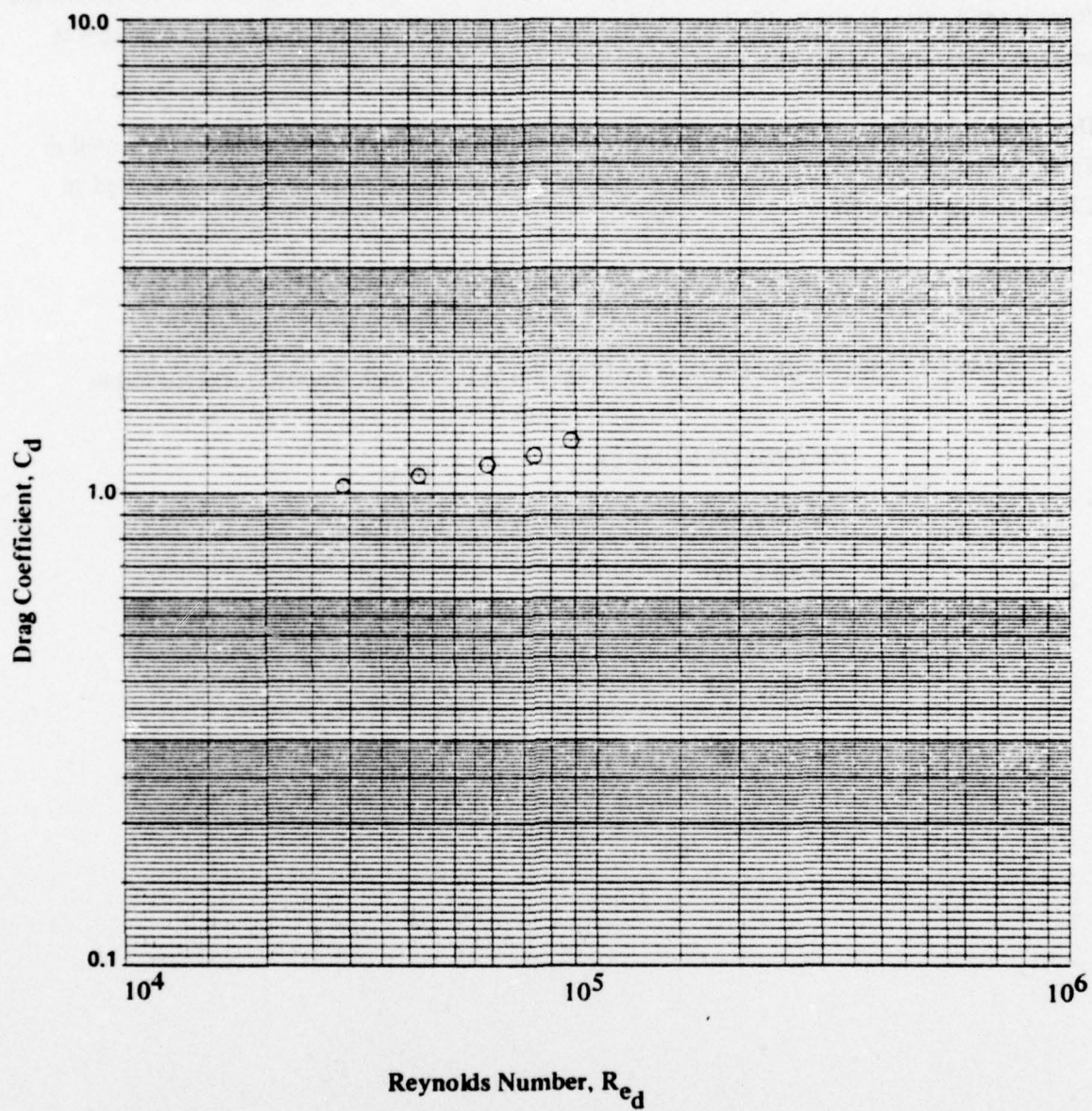


Figure 2-7. Drag Coefficient Data by Diggs for A 0.375 Inch Smooth Jacketed Cable

Table 2-8. Drag Coefficient Data by Diggs for Several Bare Double-Armored Cables

CABLES	REYNOLDS NUMBER	$C_d$
0.322 inch, 18 x 18 ↓	$2.90 \times 10^4$	1.54
	$4.25 \times 10^4$	2.03
	$5.90 \times 10^4$	1.91
0.542 inch, 24 x 24 ↓	$8.40 \times 10^4$	0.30
	$4.30 \times 10^4$	1.27
	$7.17 \times 10^4$	1.74
0.840 inch, 24 x 24 ↓	$9.80 \times 10^4$	3.60
	$1.14 \times 10^5$	2.05
	$1.43 \times 10^5$	1.84
	$7.20 \times 10^4$	0.82
	$1.06 \times 10^5$	1.03
	$1.43 \times 10^5$	1.44
	$1.76 \times 10^5$	2.00
	$6.35 \times 10^4$	1.91
	$9.70 \times 10^4$	1.84
	$1.26 \times 10^5$	1.92
	$6.80 \times 10^4$	1.55
	$1.03 \times 10^5$	1.40
	$1.34 \times 10^5$	1.39
	$1.70 \times 10^5$	1.18
	$7.50 \times 10^4$	1.71
	$1.05 \times 10^5$	1.61
	$1.42 \times 10^5$	1.70
	$1.76 \times 10^5$	1.91

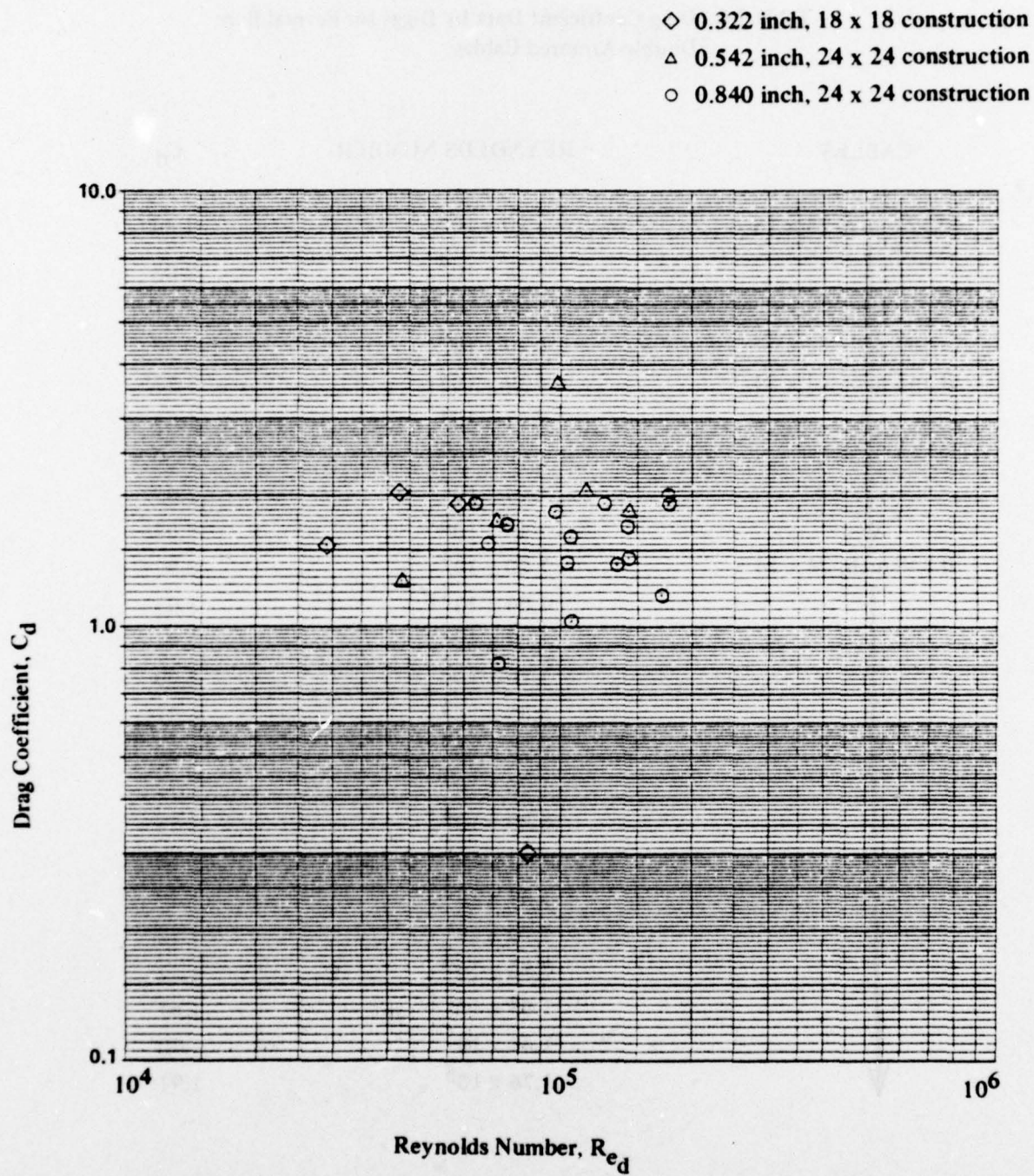


Figure 2-8. Drag Coefficient Data by Diggs for Several Bare Double-Armored Cables

## 2.7 DATA ITEM 7

**Source:** Charnews, D. P., "Drag Coefficients of Vibrating Synthetic Rope", MIT/WHOI, September, 1971.

**Cables Tested:** Four (4) synthetic ropes, all without jackets, were tested by Charnews. Three (3) of the ropes were of a plaited construction and the remaining rope was of a single braided construction. The cables tested are identified as follows:

- a. 9/16 inch, nylon, 8 strand plaited
- b. 5/8 inch, nylon, 8 strand plaited
- c. 3/4 inch, nylon, 8 strand plaited
- d. 3/8 inch, dacron, single braided.

**Experimental Procedure:** The tests were conducted at the Variable Pressure Water Tunnel at the Massachusetts Institute of Technology. The cables passed through the tunnel test section and were maintained under tension with a tensioning frame. The drag force on the rope was measured using a strain gauge dynamometer. The frequency of cable vibration was determined with a stroboscopes. Drag measurements were made for each rope for various cable tension (50 pounds to 2000 pounds) and water speeds. In addition, the diameter of the rope was measured at each tension step.

**Assessment of the Data:** The original purpose of the experiments was to measure the drag of vibrating synthetic ropes. However, due to the bearing surfaces used to measure the drag, the cables only vibrated at low tensions. The majority of the data was for non-vibrating conditions. Only the non-vibrating data are presented in this report. Except for the data points at the low Reynolds Numbers where considerable scatter can be noticed, the data shows good agreement for all tensions and diameters. The scatter at the low Reynolds Numbers which corresponds to low water speeds is probably due to the low values of drag which were measured.

**Drag Coefficient Data:** The tabulated and plotted drag coefficient data are based upon the actual cable diameter under load as measured by the investigator and not the nominal diameter. The data for the three (3) plaited ropes are presented in Table 2-9 and Figure 2-9. Since all of the plaited ropes are of identical construction and good agreement exists between the data for the three different diameters, the plotted data values are presented without distinguishing one diameter from another. The data for the 3/8-inch single braided rope are presented in Table 2-10 and Figure 2-10.

Table 2-9. Drag Coefficient Data by Charnews for Several Plaited,  
Synthetic Ropes


DIAMETER	REYNOLDS NUMBER	$C_d$
9/16 inch 	$4.536 \times 10^3$	0.794
	$9.072 \times 10^3$	0.992
	$1.456 \times 10^4$	1.001
	$1.910 \times 10^4$	0.985
	$2.387 \times 10^4$	0.974
	$2.889 \times 10^4$	0.959
	$3.342 \times 10^4$	0.965
	$3.820 \times 10^4$	0.963
	$4.297 \times 10^4$	0.964
	$4.775 \times 10^3$	1.433
	$9.550 \times 10^3$	1.075
	$1.456 \times 10^4$	1.001
	$1.934 \times 10^4$	1.048
	$2.387 \times 10^4$	1.003
	$2.889 \times 10^4$	0.959
	$3.342 \times 10^4$	0.936
	$3.820 \times 10^4$	0.940
	$4.250 \times 10^4$	0.922
	$4.775 \times 10^4$	0.931
	$4.729 \times 10^3$	1.447
	$9.458 \times 10^3$	1.085
	$1.419 \times 10^4$	0.964
	$1.915 \times 10^4$	0.970
	$2.412 \times 10^4$	0.973
	$2.837 \times 10^4$	0.984

Table 2-9. Drag Coefficient Data by Charnews for Several Plaited,  
Synthetic Ropes (Cont.)

DIAMETER	REYNOLDS NUMBER	C <sub>d</sub>
9/16 inch ↓	$3.310 \times 10^4$	0.974
	$3.783 \times 10^4$	0.972
	$4.256 \times 10^4$	0.982
	$4.705 \times 10^4$	0.986
	$4.379 \times 10^3$	1.644
	$9.219 \times 10^3$	0.928
	$1.383 \times 10^4$	0.989
	$1.844 \times 10^4$	1.020
	$2.305 \times 10^4$	1.009
	$2.766 \times 10^4$	0.989
	$3.227 \times 10^4$	0.969
	$3.688 \times 10^4$	0.986
	$4.172 \times 10^4$	0.988
	$4.610 \times 10^4$	0.979
5/8 inch ↓	$5.528 \times 10^3$	1.253
	$1.164 \times 10^4$	0.989
	$1.804 \times 10^4$	0.882
	$2.327 \times 10^4$	0.954
	$2.909 \times 10^4$	0.905
	$4.073 \times 10^4$	0.923
	$4.655 \times 10^4$	0.989
	$5.267 \times 10^3$	1.315
	$1.053 \times 10^4$	1.150
	$1.691 \times 10^4$	1.020
	$2.246 \times 10^4$	1.049

Table 2-9. Drag Coefficient Data by Charnews for Several Plaited,  
Synthetic Ropes (Cont.)

DIAMETER	REYNOLDS NUMBER	$C_d$
5/8 inch ↓	$2.772 \times 10^4$	1.068
	$3.327 \times 10^4$	1.038
	$3.937 \times 10^4$	0.989
	$4.436 \times 10^4$	1.010
	$5.483 \times 10^3$	1.200
	$1.069 \times 10^4$	1.104
	$1.700 \times 10^4$	0.999
	$2.221 \times 10^4$	1.024
	$2.769 \times 10^4$	1.012
	$3.345 \times 10^4$	1.000
	$3.838 \times 10^4$	0.992
	$4.386 \times 10^4$	1.003
	$5.518 \times 10^3$	1.192
	$1.104 \times 10^4$	1.043
	$1.655 \times 10^4$	1.060
	$2.262 \times 10^4$	1.028
	$2.814 \times 10^4$	0.986
	$3.311 \times 10^4$	1.010
	$3.863 \times 10^4$	0.998
	$4.415 \times 10^4$	1.015
3/4 inch ↓	$6.456 \times 10^3$	1.007
	$1.227 \times 10^4$	1.116
	$1.904 \times 10^4$	1.027
	$2.582 \times 10^4$	1.024
	$3.228 \times 10^4$	0.993

Table 2-9. Drag Coefficient Data by Charnews for Several Plaited,  
Synthetic Ropes (Cont.)

DIAMETER	REYNOLDS NUMBER	$C_d$
3/4 inch ↓	$3.873 \times 10^4$	0.993
	$4.454 \times 10^4$	1.002
	$6.210 \times 10^3$	1.108
	$1.307 \times 10^4$	1.000
	$1.994 \times 10^4$	0.968
	$2.647 \times 10^4$	1.006
	$3.268 \times 10^4$	0.980
	$3.922 \times 10^4$	0.972
	$4.575 \times 10^4$	0.949
	$5.229 \times 10^4$	0.945
	$6.584 \times 10^3$	1.004
	$1.284 \times 10^4$	0.924
	$1.975 \times 10^4$	1.004
	$2.634 \times 10^4$	1.004
	$3.325 \times 10^4$	0.985
	$3.950 \times 10^4$	0.990
	$4.609 \times 10^4$	0.974
	$5.267 \times 10^4$	0.973

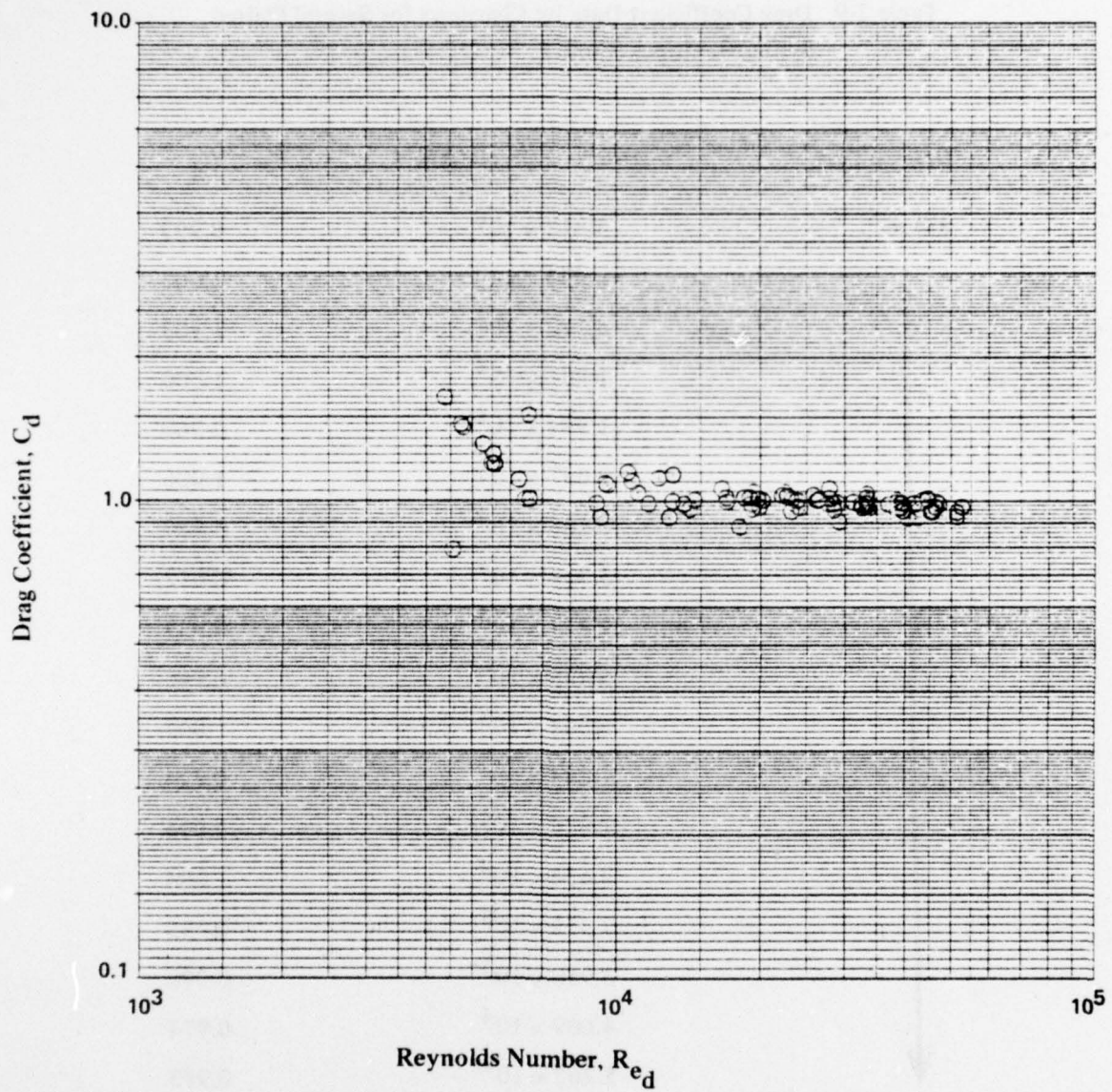


Figure 2-9. Drag Coefficient Data by Charnews for Several Plaited Synthetic Ropes

Table 2-10. Drag Coefficient Data by Charnews for A  
3/8 Inch Single Braided Synthetic Line

REYNOLDS NUMBER	$C_d$
$2.957 \times 10^3$	1.099
$5.915 \times 10^3$	0.824
$9.168 \times 10^3$	1.029
$1.213 \times 10^4$	1.111
$1.508 \times 10^4$	1.141
$1.789 \times 10^4$	1.201
$2.085 \times 10^4$	1.105
$2.381 \times 10^4$	1.153
$3.119 \times 10^3$	0.947
$5.670 \times 10^3$	1.146
$8.789 \times 10^3$	1.073
$1.162 \times 10^4$	0.955
$1.446 \times 10^4$	1.014
$1.729 \times 10^4$	1.078
$2.013 \times 10^4$	1.069
$2.297 \times 10^4$	1.171
$3.119 \times 10^3$	1.895
$5.812 \times 10^3$	1.364
$8.789 \times 10^3$	1.193
$1.162 \times 10^4$	1.227
$1.446 \times 10^4$	1.278
$1.729 \times 10^4$	1.140
$1.999 \times 10^4$	1.084
$2.297 \times 10^4$	1.031

Table 2-10. Drag Coefficient Data by Charnews for A  
3/8 Inch Single Braided Synthetic Line (Cont.)

REYNOLDS NUMBER	$C_d$
$2.835 \times 10^3$	1.146
$5.670 \times 10^3$	1.146
$8.647 \times 10^3$	1.109
$1.162 \times 10^4$	1.159
$1.446 \times 10^4$	1.146
$1.729 \times 10^4$	1.140
$2.013 \times 10^4$	1.114
$2.297 \times 10^4$	1.153

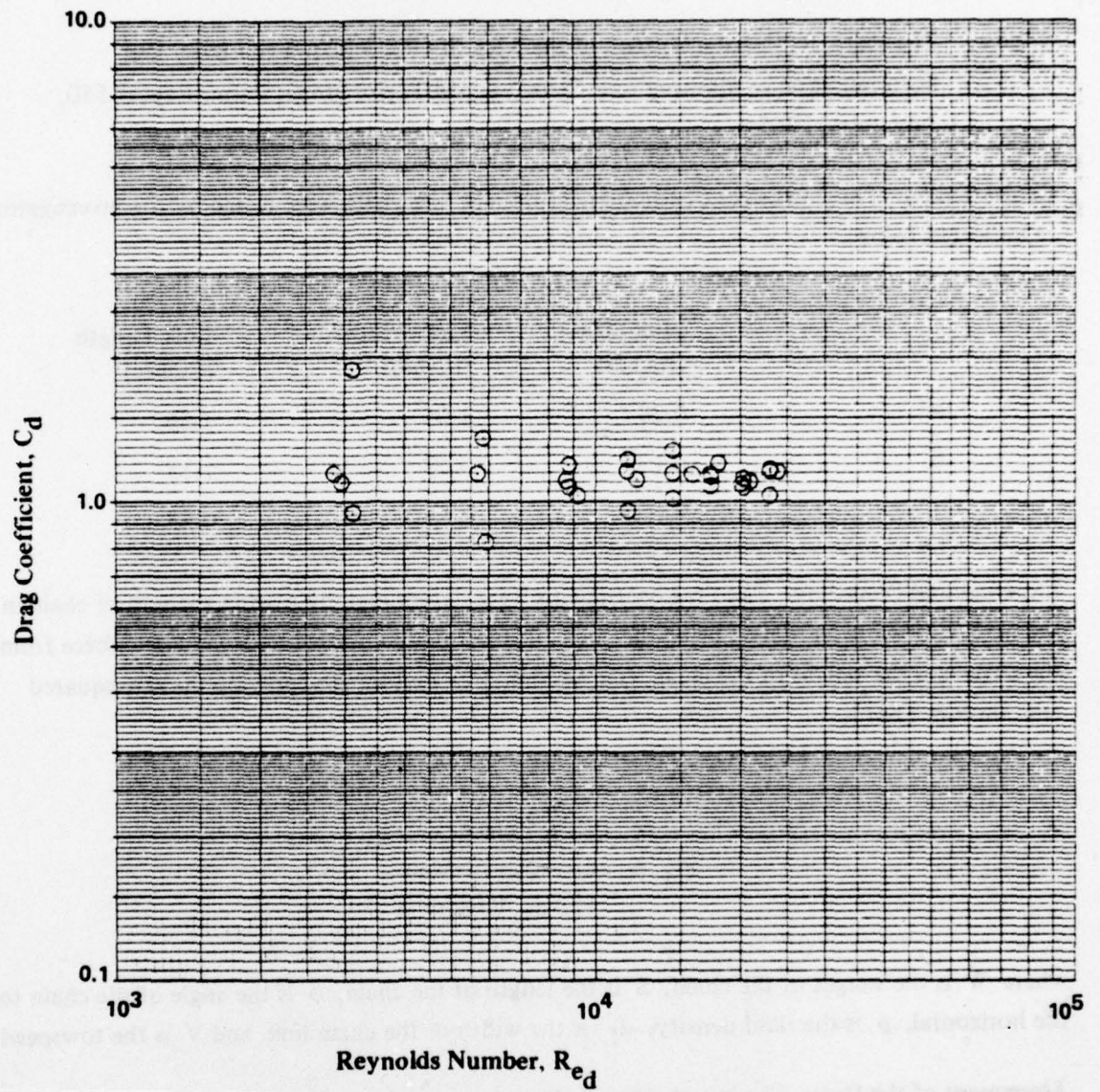


Figure 2-10. Drag Coefficient Data by Charnews for A  
3/8 Inch Single Braided Synthetic Rope

## 2.8 DATA ITEM 8

**Source:** Eisenberg, P., "Characteristics of the NRL MARK 3 Boat-Type Buoy and Determination of Mooring Line Sizes", David Taylor Model Basin, Report 550, September 1945.

**Cables Tested:** Three (3) sizes of commercial straight link chain were tested by the investigator as indicated below.

	Link Size (Inches)	Link Width (Inches)	Link Length (Inches)
a.	0.28	1.05	1.56
b.	0.19	0.68	1.15
c.	0.15	0.54	0.88

**Experimental Procedure:** The drag coefficients were determined by towing a length of chain in the NSRDC towing basin measuring the angle, computing the normal hydrodynamic force from the angle and the weight of the chain, (see Section 2.2), and finally applying the sine-squared relationship. That is

$$C_d = \frac{\frac{W}{S} \cos \phi}{\frac{1}{2} \rho d_L V^2 \sin^2 \phi}$$

where  $W$  is the weight of the chain,  $S$  is the length of the chain,  $\phi$  is the angle of the chain to the horizontal,  $\rho$  is the fluid density,  $d_L$  is the width of the chain link, and  $V$  is the towspeed.

**Assessment of the Data:** The investigator made no mention of the chain vibrating. Again, a sine-squared relationship was used to compute the drag coefficient data. The document does not give sufficient information to compute the towing angles, however, it is suspected that the angles measured were greater than 25 degrees and the sine-squared relationship is probably a reasonable assumption.

**Drag Coefficient Data:** Tabulated values of the drag coefficient data for the three (3) sizes of straight link chain tested are presented in Table 2-11. Plotted values are presented in Figure 2-11. Note that the drag coefficients and Reynolds Numbers are based upon the width of the chain link.

Table 2-11. Drag Coefficient Data by Eisenberg for Straight Link Chain

CHAIN WIDTH	REYNOLDS NUMBER	$C_d$
1.05 inch ↓	$2.7 \times 10^4$	0.85
	$5.4 \times 10^4$	0.93
	$8.2 \times 10^4$	0.86
	$8.2 \times 10^4$	0.89
	$9.5 \times 10^4$	0.93
	$9.5 \times 10^4$	0.96
	$1.09 \times 10^5$	0.91
	$1.09 \times 10^5$	0.98
0.68 inch ↓	$1.37 \times 10^5$	0.90
	$1.8 \times 10^4$	0.79
	$3.5 \times 10^4$	0.83
	$5.3 \times 10^4$	0.84
	$5.3 \times 10^4$	0.87
0.54 inch ↓	$7.1 \times 10^4$	0.96
	$1.4 \times 10^4$	0.70
	$2.1 \times 10^4$	0.74
	$2.9 \times 10^4$	0.82
	$3.5 \times 10^4$	0.88
	$4.2 \times 10^4$	0.91

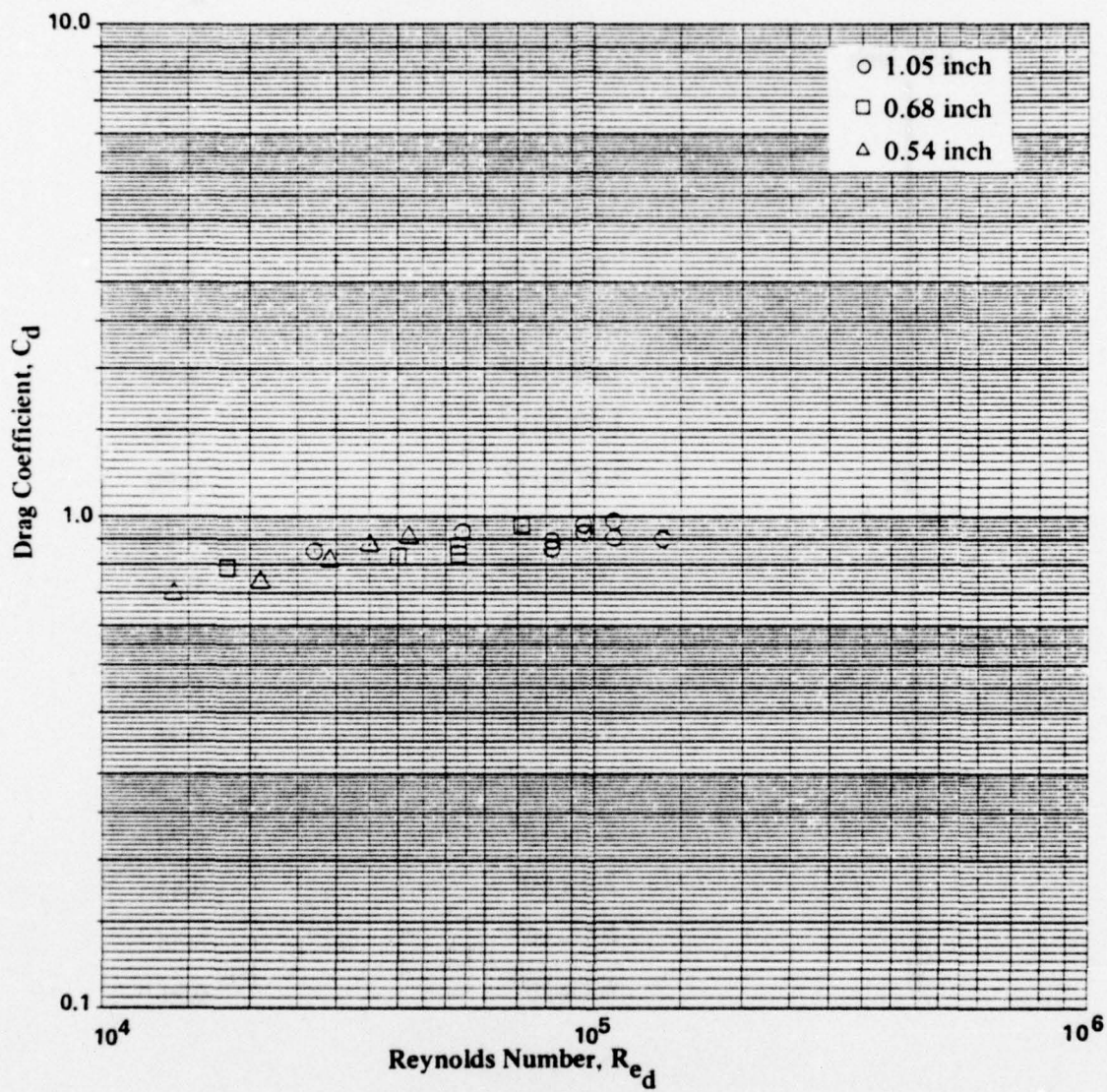


Figure 2-11. Drag Coefficient Data by Eisenberg Based on Chain Width for Straight Link Chain

## 2.9 DATA ITEM 9

**Source:** Bonde, L.W., "Determination of Stud Link Anchor Chain (Die-Lock Type) Drag Coefficients From Tow Test Data", Hydrospace Research Corporation, Report No. 133, November 1965.

**Cables Tested:** Three (3) sizes of stud link chain were tested as indicated below.

	CHAIN SIZE (Inches)	LINK WIDTH (Inches)	LINK LENGTH (Inches)
a.	3/4	2.69	4.5
b.	1	3.59	6.0
c.	1 1/4	4.50	7.5

Each stud link chain was of the die-lock type.

**Experimental Procedure:** Seventy (70) foot lengths of chain were towed from the stern of a small boat. Measurement of the weight of the chain, the towspeed, and the towing angle of the chain were made. The drag coefficients were computed from the balance of the forces acting normal to the chain with a sine-squared relationship applied. (See Sections 2.2 and 2.8.)

$$C_d = \frac{W \cos \phi}{\frac{1}{2} \rho d V^2 \sin^2 \phi}$$

The investigator presented the data for the drag coefficients and Reynolds Numbers in terms of the chain size.

**Assessment of the Data:** The investigator made no mention of the chain vibrating during the tow tests. The chain was towed at angles as shallow as 10 degrees and it is felt that the sine-squared relationship does not hold true for angles that shallow, especially when the shape of chain as compared to a wire rope or synthetic rope is considered. As a result, that portion of the data corresponding to angles below 20 degrees are not included in this report. Another reason for not including that portion of the data is the boat wake noted by the investigator which affected the chain when towing at the higher speeds (i.e., shallow towing angles).

**Drag Coefficient Data:** The tabulated and plotted drag coefficient data are presented in Table 2-12 and Figure 2-12, respectively. It should be noted that, although the investigator presented the drag coefficient and Reynolds Number data in terms of the chain size, that data have been recomputed and are presented herein in terms of the link width in order to be consistent with the data by Eisenberg (Section 2.8).

**Table 2-12. Drag Coefficient Data by Bonde for Stud Link Anchor Chain**

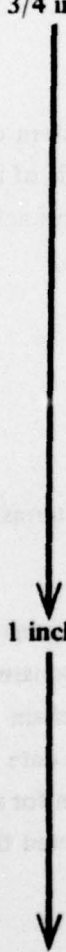
CHAIN SIZE	REYNOLDS NUMBER (Based on Chain Width)	$C_d$ (Based on Chain Width)
 3/4 inch	$1.07 \times 10^5$	0.87
	$1.58 \times 10^5$	0.78
	$1.61 \times 10^5$	0.81
	$1.79 \times 10^5$	0.63
	$1.83 \times 10^5$	0.60
	$2.04 \times 10^5$	0.60
	$2.27 \times 10^5$	0.84
	$2.36 \times 10^5$	0.74
	$2.36 \times 10^5$	0.77
	$2.76 \times 10^5$	0.88
	$3.15 \times 10^5$	0.91
	$3.15 \times 10^5$	0.95
	$1.26 \times 10^5$	0.89
	$1.26 \times 10^5$	0.92
	$1.40 \times 10^5$	0.74
	$1.54 \times 10^5$	0.90
1 inch	$1.54 \times 10^5$	0.92
	$1.80 \times 10^5$	0.96
	$1.80 \times 10^5$	0.97

Table 2-12. Drag Coefficient Data by Bonde for Stud Link Anchor Chain (Cont.)

CHAIN SIZE	REYNOLDS NUMBER (Based on Chain Width)	$C_d$ (Based on Chain Width)
1 inch ↓	$1.90 \times 10^5$	0.85
	$2.01 \times 10^5$	0.65
	$2.05 \times 10^5$	0.88
	$2.23 \times 10^5$	0.83
	$2.37 \times 10^5$	0.88
	$2.48 \times 10^5$	0.78
	$2.50 \times 10^5$	0.67
	$2.51 \times 10^5$	0.90
	$2.59 \times 10^5$	0.82
	$2.87 \times 10^5$	0.85
	$2.91 \times 10^5$	0.78
	$2.94 \times 10^5$	0.90
	$2.96 \times 10^5$	0.95
	$3.09 \times 10^5$	0.88
	$3.30 \times 10^5$	0.82
	$3.45 \times 10^5$	0.88
	$3.45 \times 10^5$	0.99
	$3.59 \times 10^5$	0.93
	$3.59 \times 10^5$	0.74
1 1/4 inch ↓	$2.16 \times 10^5$	0.81
	$2.48 \times 10^5$	0.72
	$2.52 \times 10^5$	0.64
	$2.56 \times 10^5$	0.69
	$2.63 \times 10^5$	0.79
	$3.24 \times 10^5$	0.81
	$3.31 \times 10^5$	0.78

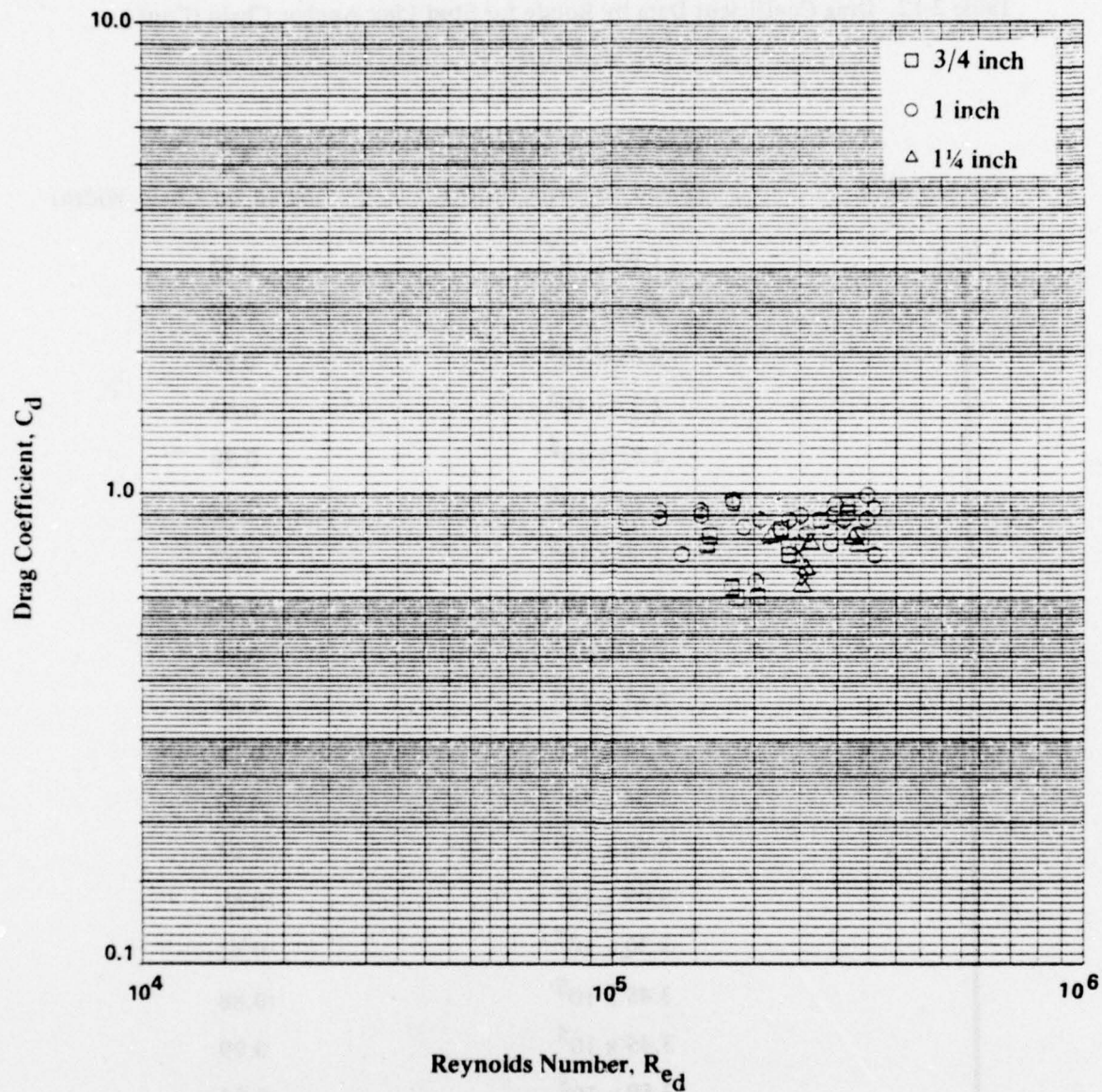


Figure 2-12. Drag Coefficient Data by Bonde Based Upon Chain Width for Stud Link Chain (Die-Lock Type)

## 2.10 DATA ITEM 10

**Source:** Kretschmer, T.R., Edgerton, G.A. and Albertson, N.D., "Seafloor Construction Experiment, SEACON II - An Instrumented Tri-Moor for Evaluating Undersea Cable Structure Technology," Civil Engineering Laboratory, Naval Construction Battalion Center, Technical Report R - 848, December 1976.

**Cables Tested:** The SEACON II cable consists of a 0.50 inch 3x19 wire rope with a polyethylene jacket giving an overall outer diameter of 0.72 inches.

**Experimental Procedure:** The SEACON II cable was tested at two separate facilities. The majority of the data were taken in the Naval Post Graduate School water tunnel. A four (4) inch long section was tested in the water tunnel. The second set of data were measured at the Naval Ship Research and Development Center. A fifteen (15) foot section was towed in the towing basin. Both tests represent situations where the cable was oriented normal to the flow direction. In the case of the NSRDC data only the data for which the cable was observed to be non-vibrating are presented.

**Assessment of the Data:** The data have been verified to be measurements of a non-vibrating cable. The lack of scatter would indicate that the quality of the data is quite good, especially considering the data were taken in two separate tests.

**Drag Coefficient Data:** The tabulated and plotted drag coefficient data are presented in Table 2-13 and Figure 2-13.

Table 2-13. Drag coefficient Data for the SEACON II Cable

Source	Reynolds Number	$C_d$
NPGS ↓	$8.10 \times 10^2$	1.68
	$1.51 \times 10^3$	1.51
	$2.00 \times 10^3$	1.54
	$3.96 \times 10^3$	1.57
	$6.00 \times 10^3$	1.61
	$8.00 \times 10^3$	1.64
NSRDC ↓	$2.52 \times 10^3$	1.52
	$3.32 \times 10^3$	1.59
	$4.29 \times 10^3$	1.58

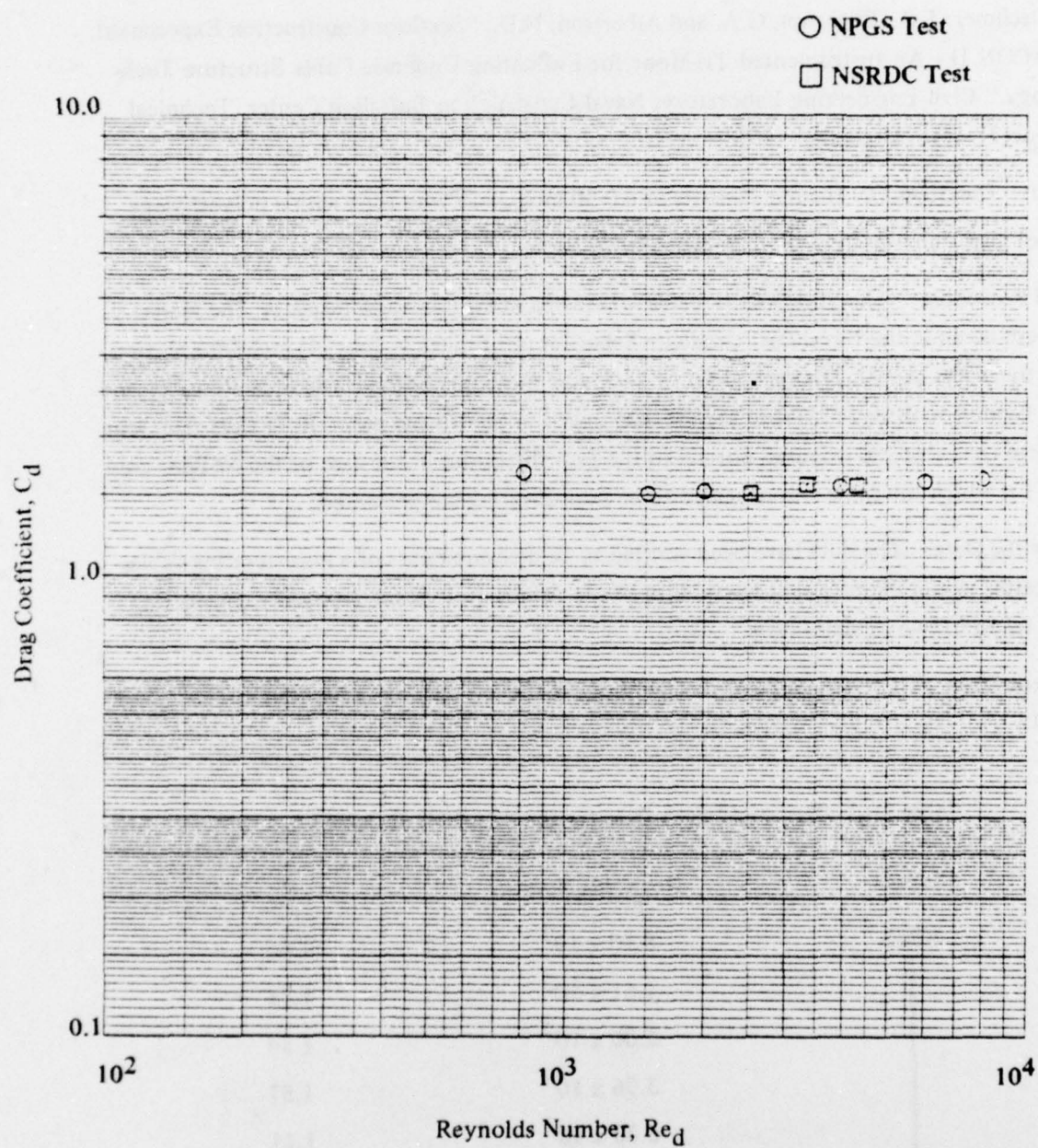


Figure 2-13. Drag Coefficient Data for the SEACON II Cable

### Section 3

#### SUMMARY OF EXISTING DRAG COEFFICIENT DATA

The purpose of this section is to summarize the drag coefficient data by type of cable and to identify the range(s) of Reynolds number for which data is lacking or inadequate.

##### 3.1 NON-JACKETED, STRANDED STEEL CABLES

The available data for non-jacketed, stranded steel cables are summarized in Figure 3-1 and represent the results of the following investigators and/or sources: Relf and Powell, Pode, Schultz, DTMB, and Diggs.

As a baseline reference for comparison, an empirical relationship between normal drag coefficient and Reynolds number, for a smooth circular cylinder of infinite length and in a uniform flow field, is illustrated by the Wieselsberger curve (full-line). The Wieselsberger curve is widely accepted as a valid baseline for cable normal drag comparison. Also shown is a representative curve (dash-line) of a stranded cable, developed by Wilson, reference 84, from the towing test data of Zajac, reference 87; Pode, reference 60, Mosely (1952); and Kullenberg (1951). It should be noted that the data utilized to formulate this curve, were from towing configurations in the critical angle regime and that the sine-squared law was utilized to compute the normal drag coefficients. As mentioned earlier, results of this type of analysis are of questionable validity.

It is a very difficult task to make an assessment of the data shown in Figure 3-1 as to the value of the data for use in computer programs. As a potential user of the data, it is not clear what drag coefficient should be selected for a given Reynolds number. All of the cables for which data is included are of sufficient similarity in construction. All of the cables are of 7 x 7 (or 6 x 7 with an independent core) construction or greater, and therefore, have a relatively circular cross-section. No cables having a largely different cross-section than circular (e.g., 3 x 19) are represented in the family of data. Therefore, it is felt that the construction of the cable is not a major factor in the scatter of data shown in Figure 3-1.

Based upon knowledge of the experimental procedures used by the various investigators, certain statements can be made concerning the data. First, a large percentage of the data by Diggs is certainly influenced by cable vibrations. This is probably also the case for Pode's data. Second, the data by Pode and Diggs are also affected by the fact that the data represent a very shallow

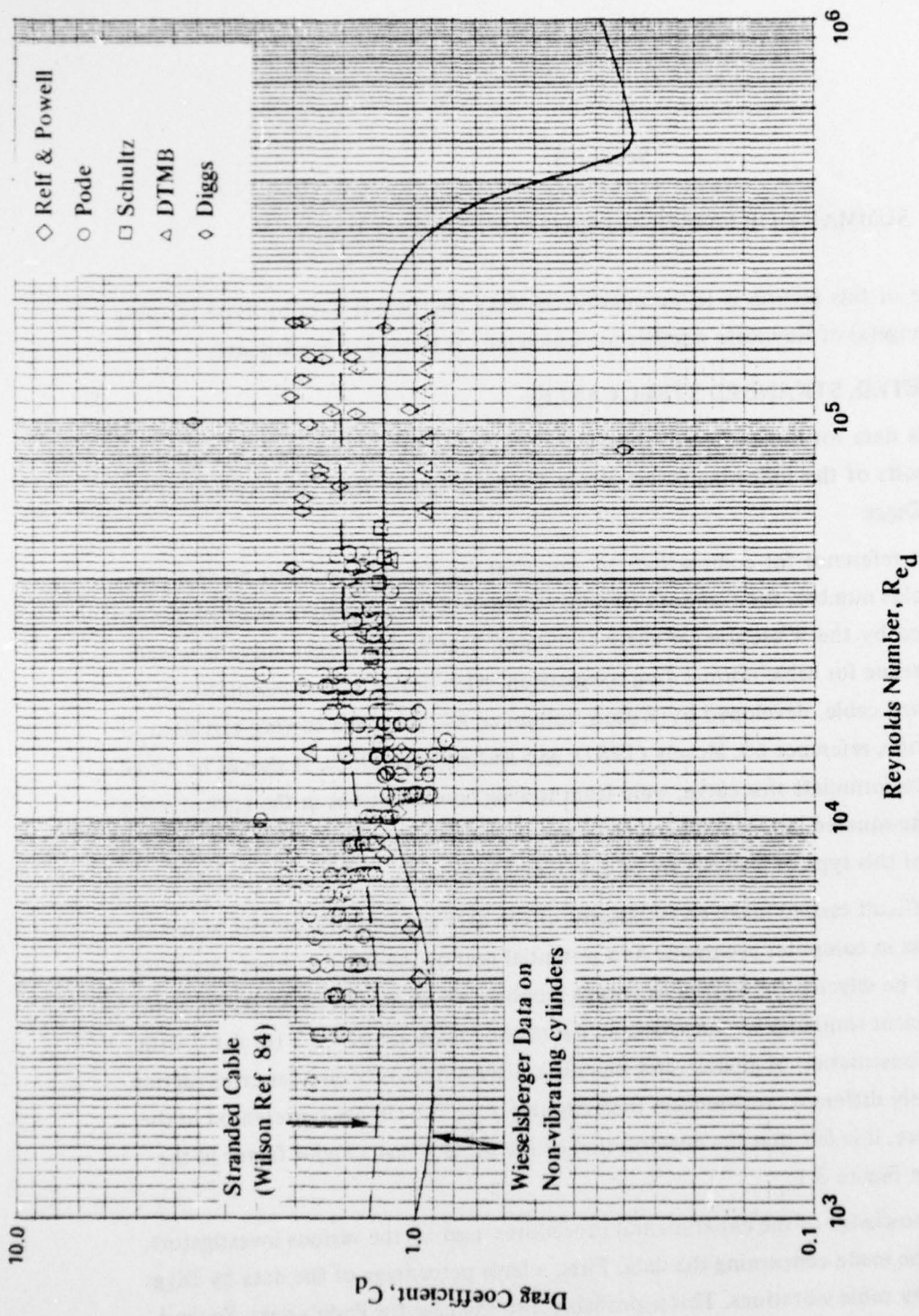


Figure 3-1. Summary of Drag coefficient Data for Non-Jacketed, Stranded Steel Cables

angle towing regime (critical angle). The inherent inaccuracy of the computed drag coefficient (a large error is possible) due to a small error in the measurement of the cable angle, and the uncertainty of the sine-squared principle for small cable angles both lend little credibility to the data. The DTMB data are slightly suspect due to possible three-dimensional data by Relf & Powell. The data by Schultz are believed to be of good quality, however, the amount of data (a total of ten (10) points over the Reynolds Number range from  $4.5 \times 10^3$  to  $5.3 \times 10^4$ ) is felt inadequate to justify its use. Finally, no data covering the Reynolds Number range from  $10^2$  to  $2 \times 10^3$  have been identified.

### 3.2 JACKETED CABLES

The available data for jacketed cables are summarized in Figure 3-2. No data were identified during the survey which cover the Reynolds Number range from  $1 \times 10^2$  to  $8 \times 10^2$ . *With the exception of the SEACON II cable data*, due to the large scatter of the data shown in Figure 3-2 covering the Reynolds Number range for  $8 \times 10^3$  to  $9 \times 10^4$  and since those data were all derived from shallow angle tow tests, it is felt that the data are inadequate for use in computer simulations requiring drag coefficients for non-vibrating jacketed cables. The SEACON II data are adequate for use in the computer simulations and the average value over the Reynolds Number range from  $8 \times 10^2$  to  $8 \times 10^3$  is 1.55.

### 3.3 SYNTHETIC ROPES

The available data for synthetic ropes are summarized in Figure 3-3. It can be seen that the drag coefficients for the braided ropes are slightly higher than for the plaited rope. Although only a single investigator could be identified for synthetic ropes (i.e., Charnews), it is felt that the data covering the range from  $6 \times 10^3$  to  $5.3 \times 10^4$  for plaited rope and the range from  $3 \times 10^3$  to  $2.4 \times 10^4$  for braided rope are adequate for use in computer simulations requiring drag coefficients of non-vibrating cables.

No data could be found for synthetic ropes having stranded or parallel lay constructions.

### 3.4 CHAIN

The available drag coefficient data for chain are summarized in Figure 3-4. It is felt that the data shown are adequate over the Reynolds Number ranges shown. Data are lacking for straight link chain in the Reynolds Number range from  $10^2$  to  $1.4 \times 10^4$ . Data are lacking for stud link chain in the Reynolds Number range from  $10^2$  to  $10^5$ .

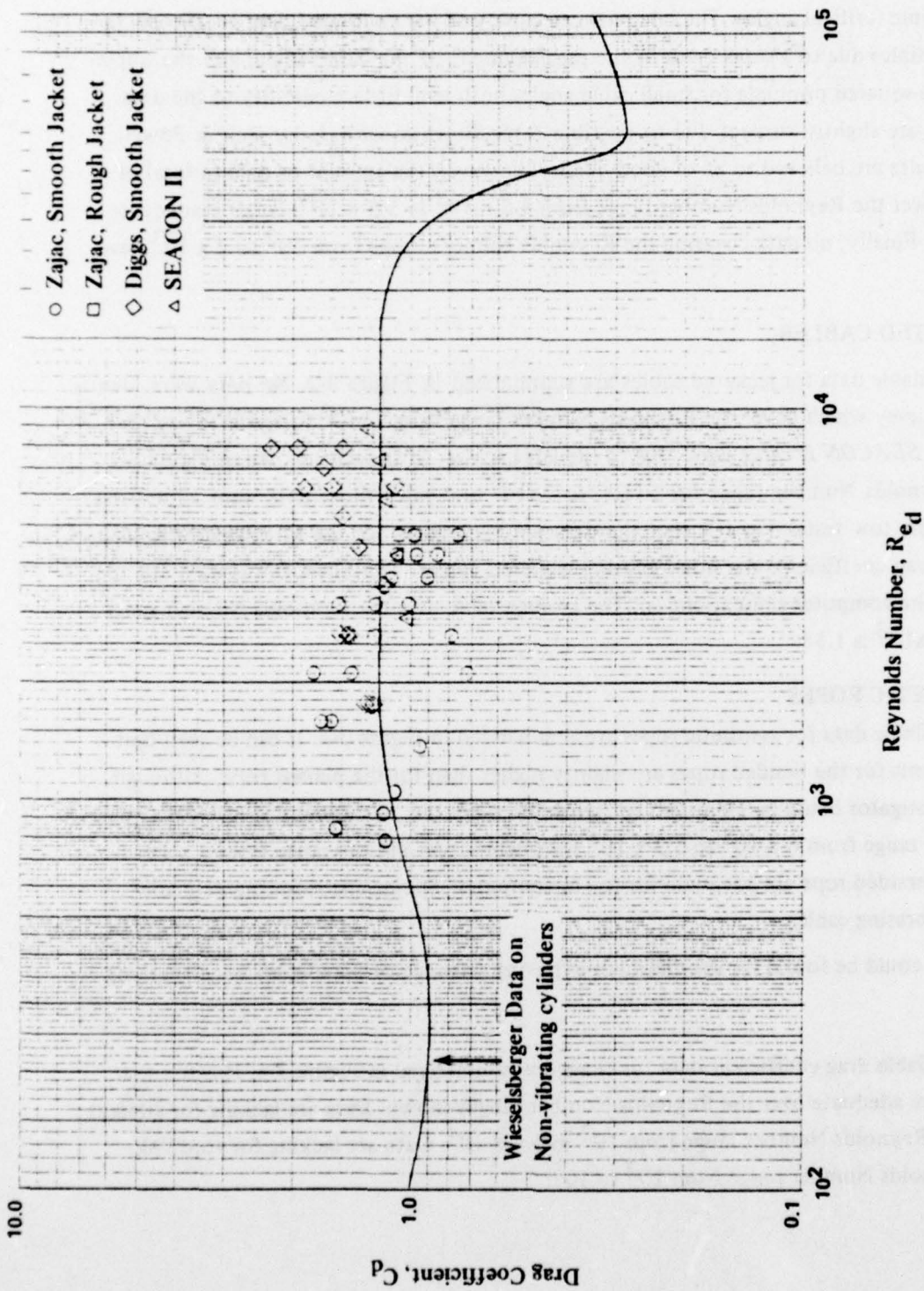


Figure 3-2. Summary of Drag Coefficient Data for Jacketed Steel Cables

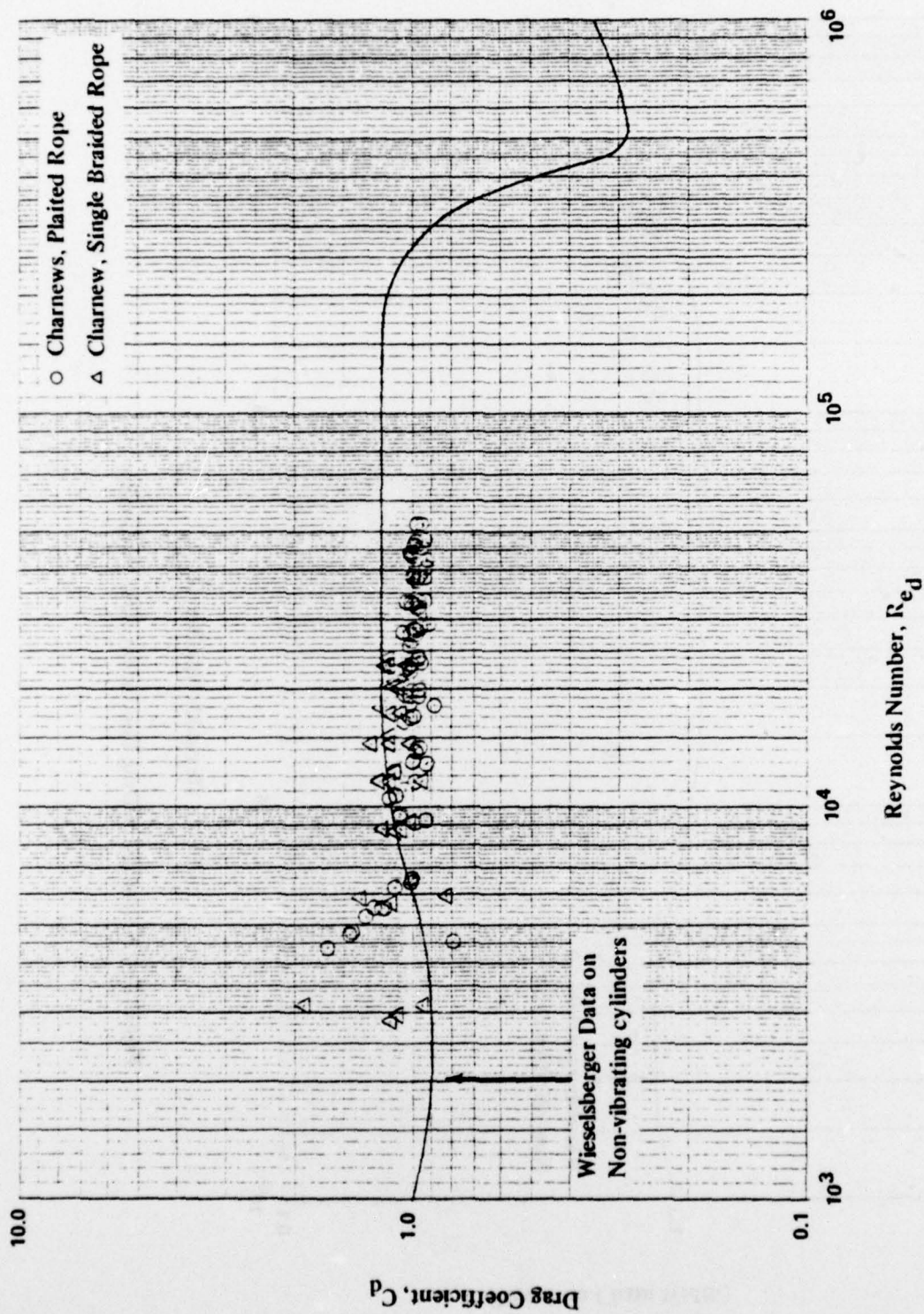


Figure 3-3. Summary of Drag Coefficient Data for Synthetic Ropes

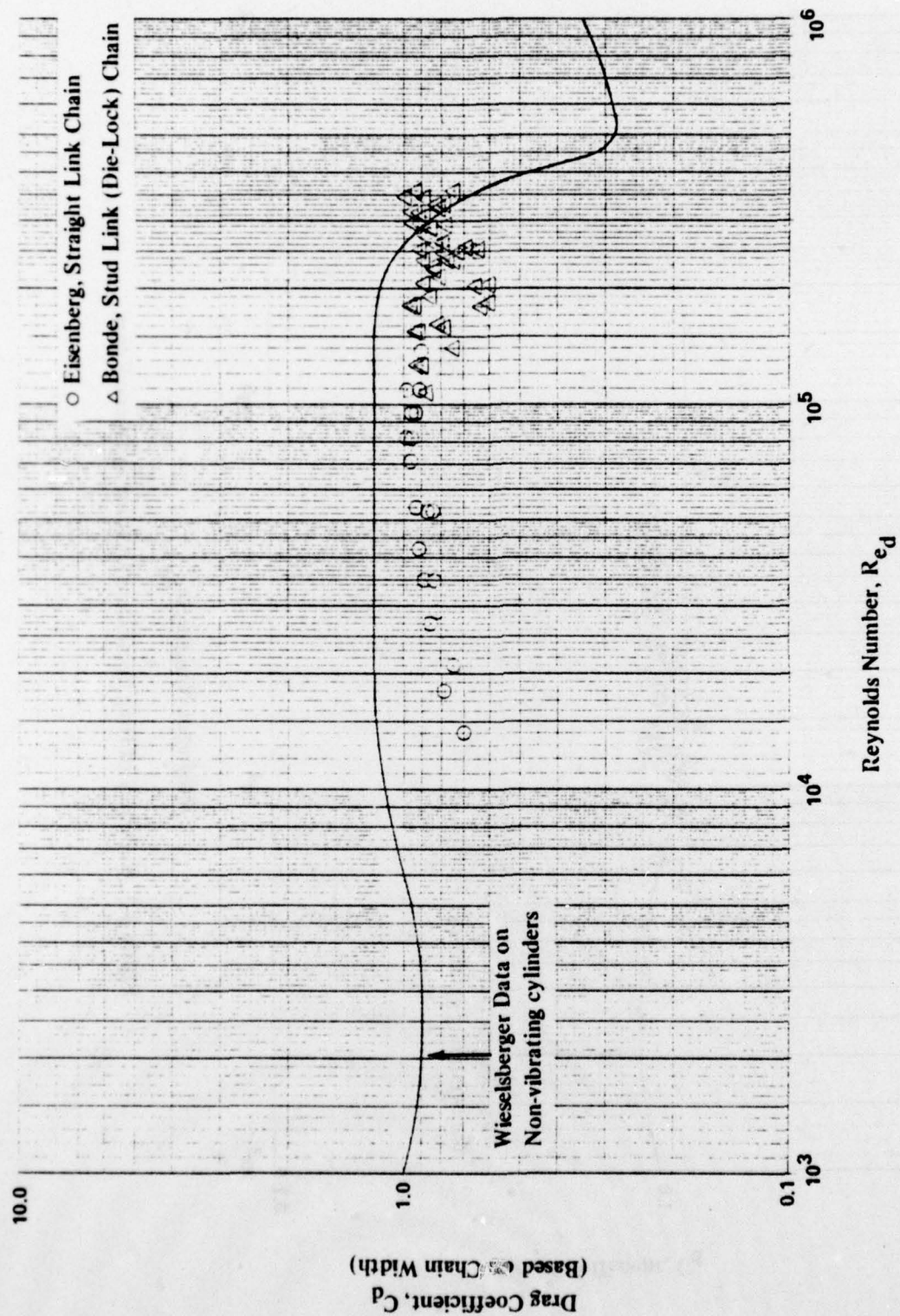


Figure 3-4. Summary of Drag Coefficient Data for Chain

#### Section 4

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